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Manned Undersea Science and Technology Fiscal Year 1973 Report

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

U.S. DEPARTMENT OF COMMERCE
Frederick B. Dent, Secretary

National Oceanic and Atmospheric Administration
Robert M. White, Administrator

Manned Undersea Science and Technology

Fiscal Year 1973 Report

MAY 1974

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Introduction and Summary

This, the second annual report of the Manned Undersea Science and Technology (MUS&T) Program of the National Oceanic and Atmospheric Administration (NOAA), describes the purpose, objectives, and nature of the program and its associations with other Federal and State agencies and private and academic institutions. The purpose of the program is primarily to foster those manned underwater scientific investigations that meet the needs and requirements of NOAA and to encourage studies that may lead to improved safety and versatility of manned undersea operations. Also, the program includes liaison, advice, and support for Federal, State, and academic bodies performing manned undersea work.

Fiscal year 1973 was a year of consolidation, as the program increasingly emphasized coastal zone resources and ecological problems, and of more identification and alinement with NOAA's missions and goals and less extramural emphasis. Funding for the program was $1,000,000 in fiscal year 1973, compared with $1,500,000 in 1972 when there were 12 at-sea operations involving eight submersibles and two habitats.

One effect of the funding reduction in fiscal year 1973 was fewer submersible operations. There were three: a Hudson Canyon investigation with the *ALVIN*, a lobster fisheries research study with the *NEKTON GAMMA*, and a British Honduras carbonate platform investigation with the *NEKTON BETA*. A fourth at-sea operation was a herring spawning study which involved surface diving.

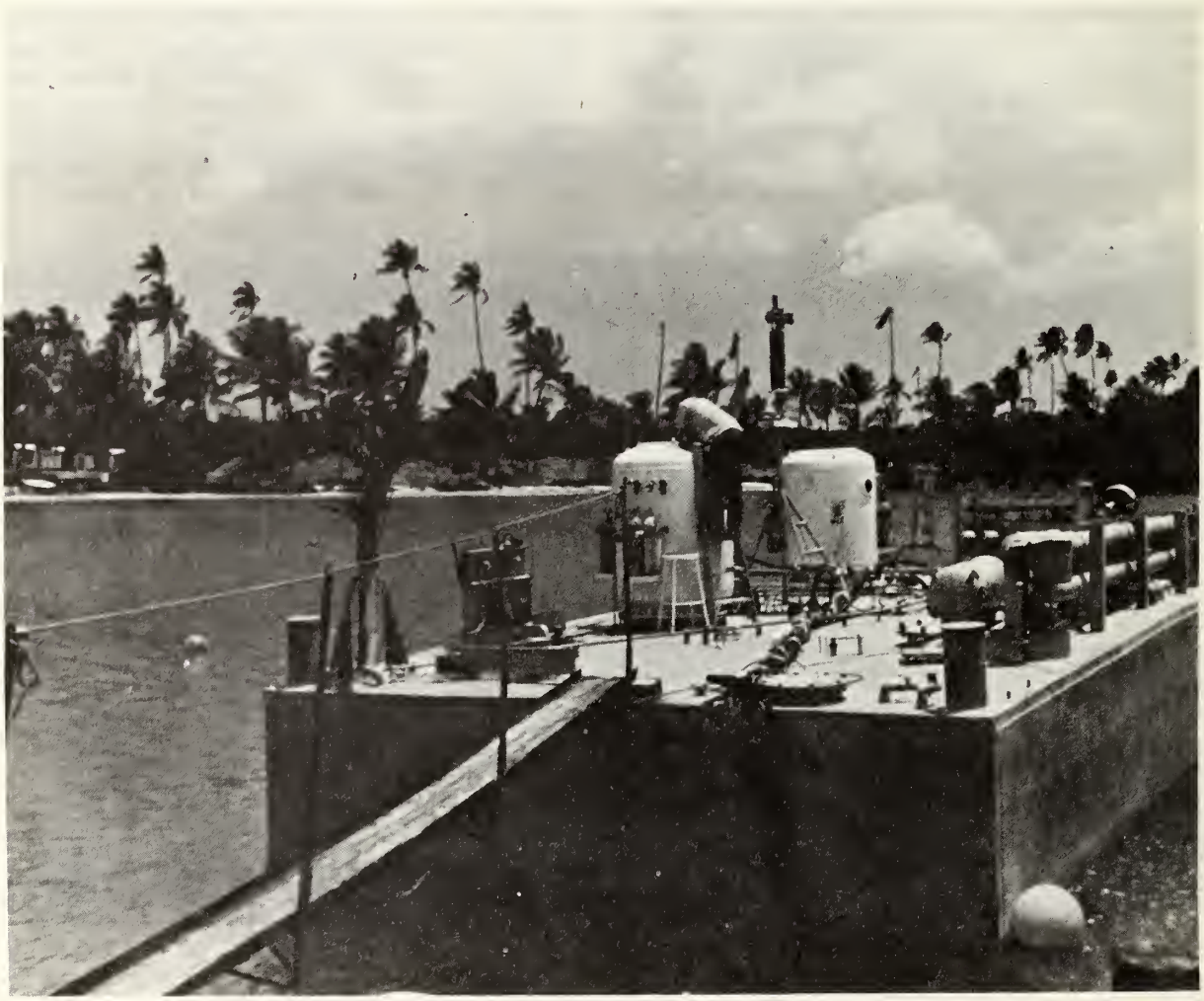
Figure 1.—Research submersible *NEKTON BETA* and support ship *SEA MARK*.

An intensive ocean floor laboratory or habitat program involving saturation diving has focused on environmental and ecological studies and other NOAA objectives. There were 27 missions using the *HYDROLAB* habitat near Freeport, Grand Bahamas, and 6 using the Puerto Rican International Underwater Laboratory (PRINUL) *LA CHALUPA* ocean floor laboratory off Puerto Rico.

In the areas of (a) Requirements and Systems Analysis and (b) Technology, several endeavors were begun or completed, namely: a National Academy of Sciences/National Academy of Engineering (NAS/NAE) workshop to assess civil manned undersea activities; a NOAA-Navy-Coast Guard study of civilian diver fatal accidents; a study of the requirements of the U.S. marine science community with respect to future underwater platforms, in particular ocean floor laboratories; a study of the status of civil manned underwater platforms and their planned use by Federal agencies; and a study under a NOAA-Navy diving physiology and biomedical research program to extend the useful range of excursions of saturated divers during science missions. A diver population study and a NOAA diving manual were started during fiscal year 1972.

Substantial progress was made in planning and preparing for international underwater endeavors. Planning was intensified for a United States-French Mid-Atlantic Ridge submersible survey program using the U.S. *ALVIN* and the French submersibles *ARCHIMEDE* and *SP3000* in mid-1974, and begun for a U.S.-French Man-in-the-Sea program. Discussions were also held with Japan and the Federal Republic of Germany for technology and science information exchange and for possible joint underwater ventures.

Figure 2.—The PRINUL underwater habitat *LA CHALUPA*.



Background

During fiscal year 1973 the role of the Manned Undersea Science and Technology (MUS&T) program became more introspective than in its first and formative year. Although acquired knowledge of the oceans' resources and processes was directed intramurally to serve NOAA's purposes in coastal zone understanding and management, extensive interaction with other organizations, particularly the academic community, resulted in benefits to the non-NOAA marine community. Also in the fiscal year, funding and charter limitations placed in abeyance the development of technological systems and equipment such as underwater laboratories, submersibles, and diver support gear. It has been a MUS&T policy to attempt to respond to requests for such facilities by working toward technology transfer from agencies such as the U.S. Navy. When this was not feasible or advisable, the facility, such as a habitat, submersible, or auxiliary gear, was leased from commercial operators.

As previously, the MUS&T program depended upon the advice and recommendations of such bodies as the National Academy of Sciences (NAS) and the National Academy of Engineering (NAE). Wherever possible, multiagency support for underwater programs was solicited, or introduced into the MUS&T projects by other agencies who wanted the MUS&T office to participate.

Unsolicited proposals, reviewed by the NOAA staff supported by external reviewers, were a major basis for decisions about support for technical and scientific projects. At least 70 percent of the FY 1973 budget was spent on contracts and grants to industry, academic institutions, and equipment suppliers.

Objectives

The basic objectives of the Manned Undersea Science and Technology (MUS&T) program are as follows:

Provide manned underwater and operational support to NOAA investigations involving marine resources and environmental problems for which subsurface observations and data collection by man are required.

Develop, support, and manage a NOAA diving program to assure safe diving and more efficient operations for prolonged manned missions on or near coastal regions and the Continental Shelf.

Synthesize the data from MUS&T-supported investigations for dissemination to the user community in order to improve understanding of the nature and availability of marine resources.

Foster and coordinate manned undersea science projects with other Federal and State agencies, industry, institutes, and universities.

Develop scientific and technical criteria for characteristics of civilian undersea facilities and platforms through the experience gained by using available habitats and submersibles.

Encourage and coordinate the transfer of undersea technology, including advances in diver technology, from the U.S. Navy when this is in the best interests of the Navy and NOAA. Also, keep abreast of general scientific and technological developments, both civilian and military, U.S. and foreign.

These objectives were achieved by a small staff of technical personnel with a recognized standing in the marine science and technology community and acquainted with Federal, industrial, and academic institutions.

Program Activities

REQUIREMENTS AND SYSTEM ANALYSIS

As part of its continuing effort to record the status and improve safety of civilian scientific diving in the United States, the MUS&T office supported five studies during fiscal year 1973 and completed in fiscal year 1974. These studies, conducted both within NOAA and under contract, are as follows:

Workshop on manned undersea activities

United States underwater fatality statistics (begun in FY 1972)

Manned underwater platform requirements

Manned underwater activities of Federal agencies and platforms utilization

Analysis of United States civilian diving population

Workshop on Manned Undersea Activities

In the spring of 1972 the Administrator of the National Oceanic and Atmospheric Administration (NOAA) requested and offered to sponsor a study by the Ocean Affairs Board of the National Academy of Sciences (NAS) and the Marine Board of the National Academy of Engineering (NAE) to review and assess civilian manned undersea activities. To implement the study, NAS-NAE assembled approximately 60 persons (about one-third each from Government, academia, and industry) in a 5-day workshop, held in October 1972. The workshop produced a valuable guidance and policy base for evaluating MUS&T plans and programs and clarified many issues and problems. Following is an excerpt of the Executive Summary from the report[1] which resulted from the workshop:

[1] National Academy of Sciences, National Academy of Engineering, *Civil Manned Undersea Activity: An Assessment.* Prepared under auspices of the Ocean Affairs Board and the Marine Board. Washington, D.C. 1973.

PROGRAMMATIC GOALS FOR CIVIL MANNED UNDERSEA ACTIVITY

In considering what the goals for a manned undersea activity program should be, the following assumptions were made by the workshop participants with respect to the total federal ocean program:

- The gross annual federal ocean program funding has leveled off.
- A shift in emphasis is likely both in funding and in agency programming.
- New federal ocean program initiatives will be examined more closely for the relevance and economic justification.
- There will be a continuing MUA program involving industry, academia, and government.
- The recent reorganization of science and technology policy advisory functions (from the White House to the National Science Foundation) will probably change the pattern of planning and organization.

The goals recommended in this report have taken these assumptions into account. Many of the goals are not exclusively MUA goals but include major areas to which MUA can contribute. The goals below are presented in four major areas: science, industry, recreation, and government.

These goals are not ordered by priority; the workshop participants considered establishment of a ranking system premature at the present development level of MUA, which is embryonic in some areas and advanced in others.

SCIENTIFIC GOALS

- Support marine biological studies, including those related to the distribution of organisms, population dynamics, behavior, environmental stress and applied fisheries problems
- Study man's physiological responses during diving to ensure safety and achieve peak performance
- Study seafloor features and geological processes, including those related to marine mineral deposits
- Investigate natural changes in the marine environment, and those resulting from man's activities
- Conduct marine archaeological studies

INDUSTRIAL GOALS

- Inspect and maintain underwater pipelines, power cables, and seafloor structures
- Perform work where manned underwater activity offers an economic advantage
- Assess and recover living and mineral marine resources
- Direct and conduct salvage operations

RECREATIONAL GOALS

- Establish underwater parks and recreational facilities
- Promote safety of water recreational equipment and operations

GOVERNMENTAL GOALS

- Provide regulations and supervision to ensure safety and accommodate related interests
- Provide supplemental support for high-cost civil MUA facilities that are beyond the funding capacity of institutional users
- Maintain a vigorous program of MUA technology exchange between military and civil areas, and assist in cooperative efforts with foreign MUA programs
- Use MUA for safety and compliance inspections of seafloor structures, and for environmental monitoring
- Sponsor research to provide increased safety for all aspects of MUA and promote research in the long-term health effects of diving
- Provide national guidelines and identify those areas where MUA can continue to contribute to the national ocean program
- Sponsor and/or provide incentives for joint programs with industry where risk or initial capital outlay is too great for private capital

To support these goals, the following technological improvements are needed:

- Increase the useful bottom time of manned submersibles and improve surface handling and underwater navigation systems
- Increase the ability to use external tools and manipulators from submersibles
- Increase the self-sufficiency of habitats
- Increase the capability and flexibility of divers
- Improve equipment and operational safety

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations were developed in the course of the study. It was agreed that a viable course of development for civil MUA must benefit the economy of the United States, contribute to our understanding of the sea environment, promote national security, and be undertaken with an understanding that the role of MUA in the accomplishment of these objectives must be evaluated with regard to other alternatives.

PRESENT AND POTENTIAL USES OF MANNED UNDERSEA ACTIVITY

Conclusions

- MUA can assist in the assessment and development of marine resources; in the establishment of standards for environmental protection of coastal waters; and in understanding environmental aspects of coastal zone management.
- MUA has demonstrated its potential in the marine sciences and in ocean engineering and work tasks in the sea.
- Civil MUA is limited more by uncertain funding than by facilities or capability. However, facilities could be improved.
- Industrial use of MUA has developed to an advanced stage in the United States with a trend toward complementary or associated use of unmanned undersea systems.
- Industry will benefit increasingly as the uses of MUA in the fields of marine biology and marine geology lead to increased capabilities in resource assessment and better environmental impact information.
- As economic advantages can be demonstrated, industry will make major commitments to MUA. At present, few areas seem to offer such potential. However, this should change as ocean engineering activities and offshore resource development mature.
- MUA should play an important role in proposed joint ocean research and utilization programs and in legal arrangements with other nations.

FACILITIES FOR MANNED UNDERSEA ACTIVITY

Conclusions

- Federally-funded selected habitats, submersibles, and support capability are needed to support civil MUA. The technology for such facilities exists, but the commitment, as well as the costs of acquisition, long-term maintenance, and operation, limit their utilization.
- Additional provisions are needed for rescue and decompression facilities to accommodate the rapid growth of recreational diving.

Recommendation

- The U.S. Government should continue to make MUA facilities available in order to support selected projects; provide experience for marine scientists and engineers; assess and use existing technology; maintain and improve the national capability and posture for future programs; offer rescue capability; evaluate and conduct missions in support of major environmental programs; and support marine resource assessment, management, and conservation.

MANAGEMENT OF CIVIL MUA PROGRAMS

Conclusions

- A single, but not exclusive, focal point within the federal government should coordinate manned undersea capabilities for civil uses, and should not only encourage but help ensure the promotion of manned undersea activity that contributes to national objectives.

- The existing organizational structure for the federal ocean program can accommodate increased activity in civil MUA.

- The government should ensure that criteria and standards for MUA utilization are established so as to ensure safe operations. Multi-agency planning and liaison with non-government agencies should help to ensure reasonable regulation. Such regulatory criteria should make sure that viable research efforts on MUA are not needlessly constrained.

Recommendations

- In order to ensure appropriate emphasis and funding and to prevent unnecessary duplication, a single federal agency that possesses the capability and charter, should take the lead in the coordination of programs with other concerned agencies and should act as the civil focal point in the U.S. Government to take on the following functions:

  ○ Assist in contracting and in the guidance of prospective suppliers of submersibles and habitats in support of the ocean science community where government participation is required.

  ○ Take the lead in an overall government and civilian assessment of the potential for use of military and industrial manned undersea activity, and develop its contribution for civil uses

  ○ Provide advisory review services to the federal government for manned undersea capabilities and activities

  NOTE: The Interagency Committee on Marine Science and Engineering recommended a similar role for NOAA in October 1972 during the review of the Federal Ocean Program, and NOAA is so serving. This action was not addressed during the course of this study, but is referenced here and in Appendix B for information only.

- The University National Oceanographic Laboratory Systems (UNOLS) could be a mechanism for coordinating the use of MUA facilities by the academic community. These facilities should include DSV's and seafloor laboratories.

- Liaison and joint operations with foreign MUA programs should be increased with a view toward greater international participation in and cooperation with U.S. programs. Several nations now maintain active programs in MUA. Joint efforts with these nations would be beneficial to civil and government MUA in the United States and should be encouraged in both the government and civilian sectors.

- A nongovernment advisory group on civil MUA should be established. A continuing assessment is needed of civil MUA as it relates to U.S. interests in the oceans. A group of qualified representatives from industry and academia should perform these functions. One particular need is to establish criteria and guidelines for MUA research, components, systems, and operations.

PROGRAMS IN MANNED UNDERSEA ACTIVITY

Conclusions

- The present state of the federal ocean program suggests that near-term growth of civil MUA will be slow unless MUA can demonstrate more convincingly an economic justification for expenditures. The reduction of Navy submersible leasing has not been matched by a comparable increase in activity of the civil agencies, leaving an excess in civilian submersible capability.

- The maximum growth area for all aspects of civil MUA will probably be in its use for systematic programs aimed at understanding the coastal zone environment and resources and the related ecology.

- Technology does not severely limit the present use of MUA. The technology being developed through industry and the Navy needs to be transferred more effectively to other sectors.

- Continued research on diver physiology and underwater medicine is required to improve safety and equipment design for endurance diving operations.

- Too few selected undersea natural areas are preserved specifically for long-term scientific study and for recreational use.

Recommendations

- Program planning for the federal ocean program should be monitored to ensure that civil MUA interests are represented, particularly when the civil sector can help solve problems in the federal program. The existing Interagency Committee on Marine Science and Engineering could expand to perform this function. The committee now coordinates 11 federal agencies that have marine interests.

- Better mechanisms are needed for the exchange of MUA technology between the Navy and the civil sector. The Navy at present has the largest MUA program, and is both the major contractor and customer to ocean science and ocean engineering. Many Navy MUA facilities could be used more effectively for civil MUA when the Navy can spare them and in accordance with current regulations.

United States Underwater Fatality Statistics, 1972

Under the sponsorship of the MUS&T office, Coast Guard Underwater Safety Project, and Navy Bureau of Medicine and Surgery, the Department of Ocean Engineering of the University of Rhode Island (URI) compiled and analyzed information on fatalities associated with underwater activities using compressed gas in the United States or which involved U.S. citizens.[2] The basic purpose of the effort is to collect statistical information on fatal accidents which will be useful to Federal agencies and other organizations with diving responsibilities, diver training organizations, equipment manufacturers, and others attempting to improve the safety of diving.

Procedure.—The primary source of initial information is a newspaper clipping service, although Coast Guard search and rescue reports, cooperating local officials, and cooperating individuals alert URI to fatalities. Report forms, which were developed through an American National Standards Institute Committee, are sent to individuals who from the newspaper report appear to have information on the accident and to local police, coroner, and similar officials. When an autopsy is performed, a copy of the report is requested.

Information on each case is compiled into one report form, and after the close of the calendar year data from the forms are compiled and analyzed to develop a summary report.

Results.—There was a modest increase in the absolute number of fatalities in calendar year 1972, compared with 1970 and 1971. There were 122 fatalities in 1972 and 116 fatalities in each of 1970 and 1971. This "increase" can be misleading with regard to overall safety since five major recreational diver training organizations independently reported that they had trained over 200,000 divers during 1972. Similarly, because of the small numbers involved, very few additional incidents can cause a rather large increase in both the absolute number and the percentage of fatalities from year to year.

A final report will be published in FY 1974, so statistics cited should be considered preliminary. Approximately half of the fatalities were in California, Florida, and Washington. California is considered to have the greatest amount of diving activity.

The distribution of fatalities by State is shown in table 1. In general, patterns have remained fairly consistent from year to year, with slight increases in the number of deaths of women and in caves and with a slight decrease in deaths of beginners. Some information is included on nonfatal accidents to which the Coast Guard responded, and very limited information on skin diving fatalities (breath-holding diving without breathing apparatus), partially caused by the problem of separating skin divers from swimmers.

Table 1.—*Scuba diving fatalities by State, 1970–72*

State	1970	1971	1972
Alabama	1	2	0
California	26	31	26
Colorado	0	1	1
Connecticut	0	0	2
Florida	22	13	26
Georgia	3	0	0
Hawaii	6	9	5
Illinois	2	0	0
Indiana	0	1	2
Kansas	0	0	1
Kentucky	0	1	0
Louisiana	5	0	1
Maine	3	3	2
Maryland	2	1	0
Massachusetts	5	4	4
Michigan	1	3	5
Missouri	3	3	2
Nebraska	0	0	1
New Hampshire	2	0	0
New Jersey	1	4	2
New York	2	11	2
Ohio	1	2	2
Oklahoma	1	0	0
Oregon	1	2	2
Pennsylvania	1	0	0
Rhode Island	2	1	2
South Carolina	0	1	1
Tennessee	0	0	1
Texas	1	4	3
Utah	2	3	0
Virginia	1	1	1
Washington	10	3	15
West Virginia	1	0	0
Wisconsin	1	4	2
Total	106	108	111

[2] Schenck, Hilbert V., Jr., and McAniff, John J., *United States Underwater Fatality Statistics, 1972,* Report URI-SSR-73-8, Department of Ocean Engineering, University of Rhode Island, Kingston, National Oceanic and Atmospheric Administration Grant 04-3-158-31.

Manned Underwater Platforms—Design And Operational Requirements

In late fiscal year 1972 the MUS&T office awarded a grant to the Engineering Design and Analysis Laboratory of the University of New Hampshire (UNH) to determine the impact of the needs of the scientific community upon the future design of manned undersea platforms, particularly underwater research and development laboratories that will be used by divers under saturation conditions.[3] The project established the following specific objectives:

Identify and classify the types of research and development programs that would use the systems

Classify the potential missions into groups of missions with each group requiring similar capabilities

Estimate the utilization rate of systems by groups

Survey the state-of-the-art of habitats and habitat technology

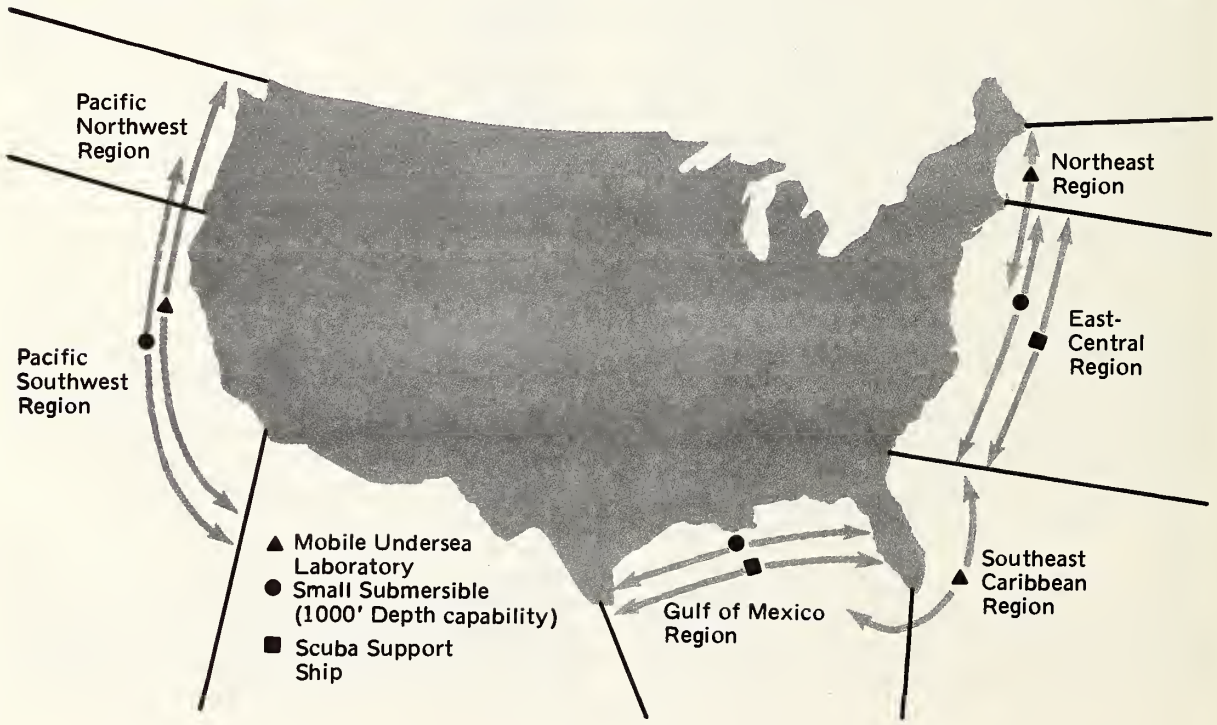
Evaluate systems against mission requirements

Develop preliminary designs of selected concepts

The effort by UNH and the Missile and Space Division of General Electric involved visiting scientists throughout the United States and concentrated on undersea laboratories (habitats with scientific divers) and submersibles. The scientists interviewed received support from many Federal agencies. The results demonstrated a current need for two submersibles without lockout, one submersible with lockout, three transportable habitats, and two scuba ships in addition to the currently accessible facilities (*HYDROLAB, PRINUL, ALVIN,* and *SEA LINK*). The geographic distribution of these facility requirements is shown in figure 3. A distinction is made between transportable and mobile habitats. A transportable habitat can be readily moved between missions, whereas a mobile habitat can move under its own power during a mission. There is a general indication that, as utilization increases, there will be a need for mobility in addition to transportability.

[3] Engineering Design and Analysis Laboratory, University of New Hampshire, *The Impact of the Requirements of the United States Scientific Diving Community on the Systems Design, Operation, and Management of Underwater Manned Platforms,* a report to the Manned Undersea Science and Technology Office of the National Oceanic and Atmospheric Administration, Department of Commerce. Technical Report 111, Contract NG 35-72. Durham, N.H., Oct. 9, 1972.

Figure 3.—Platform distribution requirements from University of New Hampshire study.



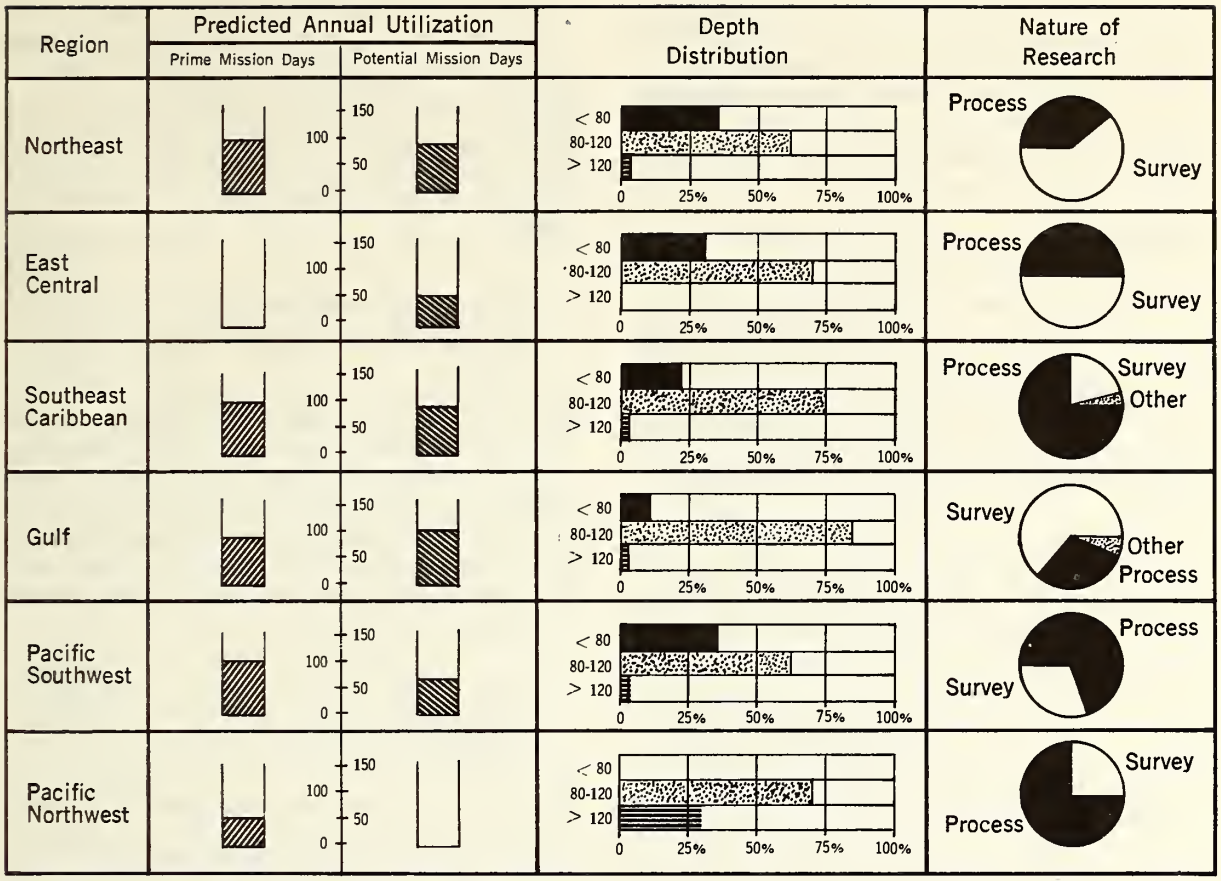


Figure 4.—Regional needs of the scientific community for utilization of underwater laboratories (study by University of New Hampshire).

With respect to the undersea laboratory, figure 4 shows the anticipated regional utilization and the nature of the underwater research. "Prime days" are the estimated days per year that could be utilized; "potential days" represent usage that would be anticipated to follow shortly thereafter if the laboratory were in place.

Conclusion.—The study recommended a Northeast system, a Pacific system, and a Florida-based system to satisfy estimated needs. The Southeast-Caribbean region and Gulf region are already serviced by *HYDROLAB* and *PRINUL;* however, *HYDROLAB's* depth limitation and *PRINUL's* restriction to Puerto Rican waters indicate the need for an additional Florida-based system.

Scuba ships are indicated for the East Central and Gulf of Mexico regions because of their utility to scientific divers and the physiographic character of the region. In both regions it is frequently necessary to travel 10 or 15 miles offshore to dive at depths exceeding 50 feet. Here, the use of a ship to support divers rather than a habitat is indicated.

Manned Underwater Activities of Federal Agencies and Utilization of Underwater Platforms

INTRODUCTION AND PURPOSE OF STUDY

In view of the decreasing use of manned undersea research submersibles and habitats (referred to herein as undersea platforms), built during the 1960's, the Interagency Committee on Marine Science and Engineering (ICMSE) requested a study to determine the Federal requirements for manned undersea activities and the extent of undersea platform use. That study was conducted by the Manned Undersea Science and Technology (MUS&T) Office of the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) during 1972. The findings were presented to the ICMSE on October 19, 1972. The study concentrated on two major aspects of the Nation's manned undersea activities. The first aspect pertained to determining those Federal marine science programs, not including

military-oriented programs, which were planning to use undersea platforms. The second aspect pertained to the status, as of October 1972, of the use and availability of manned, civilian-operated undersea research submersibles and habitats. These aspects were analyzed to determine the extent of undersea platform use that would be possible.

BACKGROUND

During the 1960's, industry invested over $100 million to develop over 50 submersible systems and three habitat systems. There were many reasons for these investments, such as to demonstrate technological capability in the competition for (primarily) Navy contracts and anticipation of substantial sales or leasing and greater oceanic exploration, exploitation, and use. The inventory and technological complexity of systems outstripped the needs of users, and the nonmission-oriented characteristics in many designs limited the utility of the systems to users. At the same time, Navy-owned systems began to meet Navy needs, and the Navy gradually withdrew support of essentially civil-oriented programs. The result was a drop in Navy lease funding from a high of approximately $2.2 million in 1968 to zero in 1971. At the time there was no civil agency focus, and a period of inactivity and decreased use of undersea platforms commenced.

At the same time, however, interest in using manned undersea platforms remained high and appeared to be increasing. A 1969 Navy study (by the Carroll committee) recorded 1,603 requests for submersibles for dives (984 by Federal agencies and 619 by academic institutions) when analyzing the use of a target $3.0 million lease fund. Of the 1,603 requests, 768 were recommended through an evaluation and priority system. Despite this interest, the recommendations of the study were not implemented.

Twelve member agencies of the ICMSE were surveyed and their findings, conclusions, and recommendations follow.

SUMMARY OF FINDINGS

Ten ICMSE member agencies reported programs; 33 programs were of a civil nature and 13 were from the Navy. In general, the survey indicated a current need for the platforms, increasing future needs, and problems in matching users, platforms, and funds. Of the 36 U.S. submersibles surveyed as of October 1972, there are only 13 civilian-operated platforms without diver lockout[4] capability and three with lockout capability which are considered part of the usable civil inventory. The extent of utilization of the usable civilian undersea platforms as of October 1972 was estimated as follows:

	Percent
Submersibles without lockout	40
Submersibles with lockout	67
Habitats	31

For example, if habitats were available for 100 dive-days, they were employed only 31 dive-days.

Based on the potential uses of the usable civilian platforms as extrapolated from current and planned programs of the Federal agencies, the use of current platforms in the FY 1974–75 (as estimated in the summer of 1972) could, if adequately funded, be raised to the following levels:

	Percent
Submersibles without lockout	86
Submersibles with lockout	167
Habitats	81

For example, operational time available on submersibles with lockout could have been increased from 100 dive-days to 167 dive-days.

The complete findings and recommendations of ICMSE will be published in FY 1974. Agencies participating in ICMSE are as follows:

Department of the Navy

U.S. Army Corps of Engineers

Department of Commerce

National Science Foundation

Department of Transportation

Department of Interior

Environmental Protection Agency

Department of State

Department of Health, Education, and Welfare

Atomic Energy Commission

National Aeronautics and Space Administration

Smithsonian Institution

[4] Lockout is a term used to describe being able to internally pressurize a submersible's compartment (separately from the operator's compartment) to a level equal to external pressure so that divers could egress into the water (within diver depth limitations).

Analysis of the United States Civilian Diving Population [5]

Because quantitative information on divers and the use of diving in the United States was limited but required for MUS&T program planning, an analysis of the U.S. civil diving population was initiated with the Technical Analysis Division of the National Bureau of Standards (NBS). The NBS Technical Analysis Division acquired most of the data and developed a significant portion of the analytic methodologies before the MUS&T office completed the study.

For the analysis, nonmilitary U.S. diving was categorized as commercial, scientific-educational-institutional, governmental, and recreational. Each category was further divided to both increase the utility of the information developed and permit the use of the most accurate methodology available within time and cost constraints. Though based largely on sampling methods, the resulting estimates are believed to be very close to the actual numbers.

Besides estimating total numbers, the analysis also examined geographic distributions, the uses made of diving, training, and expenditures on diving. In the final stages of publication, a NOAA report is expected in FY 1974 and will be available from the MUS&T office.

TECHNOLOGY PROGRAM

Introduction

The purpose of the technology program is to review and establish technical criteria for civilian manned underwater activities; provide safe and versatile submersibles, undersea laboratories, and ancillary equipment in support of undersea operations; and to formulate safe and effective procedures for man to operate in the ocean environment.

During fiscal year 1973, four submersibles and two underwater laboratories were used on MUS&T projects. In addition, one project used two trawlers for surface support of a team doing bounce diving. Underwater facilities for these projects were selected from the existing inventory by competitive procurement. No new facility developments were needed to meet the technical requirements of these missions, but assessment of undersea platforms developed by industry and the Navy is being continued.

[5] Jugel, Karl, An analysis of civil diving in the United States and the implications of the results on diver training. Presented at the ninth annual conference of the Marine Technology Society, September 1973 (paper available from MUS&T office, NOAA).

Also, the Federal civilian agencies' requirements for these facilities and their use, as recommended by the Interagency Committee on Marine Science and Engineering (ICMSE), are being coordinated in the MUS&T program. The MUS&T office is maintaining close liaison with the Navy to transfer technology from military to civil undersea applications.

This section discusses MUS&T activities in the following five general areas during this period, including technology-oriented projects sponsored or cosponsored by NOAA.

Diving technology and physiology:
Vertical excursion procedures for shallow undersea laboratories

Physiological research in support of NOAA operational diving program

The NOAA Diving Manual

Acoustic incipient bubble detection

Arctic diving expedition: equipment and human performance evaluation

Undersea habitats and laboratories
Research submersibles
Instrumentation:
Adaptation of scientific instruments for use on the sea bed

Undersea instrumentation chamber

Nuclear activation analysis

Technology transfer

Diving Technology and Physiology

VERTICAL EXCURSION PROCEDURES FOR SHALLOW UNDERSEA LABORATORIES

Principal and associate investigators.—R. Hamilton, Jr., D. Kenyon, M. Freitag, and H. Schreiner, Environmental Physiology Laboratory, Union Carbide Corporation.

To effectively work in the sea, marine scientists must have the capability of making vertical ascents and descents over a wide range of depths. Although information on working from the surface has been available for some time, little has been available regarding vertical excursions from saturated conditions until recently. When the breathing mixture used is either air or a different mix of nitrogen-oxygen, the work here described is designed to provide this kind of information.

Procedure.—A matrix was developed using known physiological data to determine allowable excursion

times from saturated depths of 30, 60, 90, and 120 ft. This matrix was then tested in two 14-day dry chamber saturation experiments. Descent and ascent excursions were made ranging from 30 to 300 ft. Excursion times ranged from 8 min to 6 hr. Whereas the subjects were saturated on a breathing mixture of nitrogen-oxygen, all excursions were made on air. Extensive physiological experimentation and medical surveillance were conducted in cooperation with researchers from the U.S. Naval Submarine Medical Research Laboratory.

Results.—As a result of these investigations, complete excursion diving tables were compiled and will be published in the forthcoming NOAA Diving Manual. No significant medical and physiological problems were encountered, and the studies will further the capability of marine scientists to operate in the oceans.

Conclusions:

Data from appropriate previous dives can be effective in advancing to new diving modes.

Descending no-stop excursion dives with air for a depth change of up to 180 ft can be made from saturation at depths to 120 ft in a normoxic nitrogen atmosphere. These excursions became more efficient with increasing habitat depth.

Efficient decompression from saturation with nitrogen can be accomplished without breathing pure oxygen by mask.

Ascending excursions of operationally useful times and depths are possible from undersea laboratories. Momentary surfacing should be considered an option for a lost or disoriented diver saturated at depths as great as 100 ft of seawater.

Adaptation to a nitrogen habitat should enable a diver to work safely while breathing air at a depth greater than he could from sea level. The extra depth is approximately equal to that of the habitat.

PHYSIOLOGICAL RESEARCH IN SUPPORT OF NOAA OPERATIONAL DIVING PROGRAM

Principal investigators.—Representatives of the U.S. Navy Submarine Medical Research Laboratory and the MUS&T office.

Aseptic bone necrosis.—Aseptic bone necrosis may be caused by tiny bubbles forming in the small blood vessels, resulting in reduced blood flow to the bones. This reduction in circulation causes portions of the bone to die. The disease is thought to be associated with the formation of residual bubbles following exposure to increased pressure such as in diving. It can also result from other maladies such as alcoholism and sickle cell anemia.

Liaison has been established with the Navy to participate directly in a long-term study for determining the development, extent, and seriousness of aseptic bone necrosis in divers. The program consists of obtaining repeated X-rays of prescribed bone and joint areas from a population of NOAA-supported divers over a period of years. To date, 40 sets of long-bone X-rays have been obtained on divers participating in NOAA missions. Thirty-four of these participated in the Puerto Rico underwater habitat program and six in the *HYDROLAB* program, both of which are described elsewhere in this report. These X-rays have been forwarded to the Navy Submarine Medical Research Laboratory, New London, for interpretation and retention and were obtained by use of a specified protocol now being used by the U.S. and British Navies. It is anticipated that the same protocol will soon be introduced and utilized in Japan. The standardization of the X-ray protocol is essential for obtaining comparable results.

NOAA DIVING MANUAL

The NOAA Diving Manual, to be completed in fiscal year 1974, is designed to meet the specialized requirements of the scientific diving programs sponsored by NOAA. The Manual will supplement, but not replace, the U.S. Navy Diving Manual and will incorporate sections of the U.S. Navy Diving Operations Handbook for offshore diving operations. The NOAA Diving Manual will prove a valuable asset to the scientist-diver as it describes in detail the procedures for various types of sophisticated equipment which the scientist requires to gather in situ data.

ACOUSTIC INCIPIENT BUBBLE DETECTION

Principal investigators.—F. Martin, J. Hudgens, J. Wenn, Ocean Research and Engineering Center, Westinghouse Electric Corporation.

Purpose and scope.—Man, when subjected to varying inert gas concentrations, must undergo inert gas saturation-desaturation within the circulatory system and all body tissues serviced by pressures. Consequently, high inert gas partial pressures—the differential between at-depth concentrations within tissue and concentrations at equilibrium with air at sea level—may be extreme. The tension thus placed upon a tissue during decompression, however, is a function not only of this differential but also of bottom time, tissue type, metabolic level, decompression profile, nature and concentration of inert gas, and other factors, such as variations in body type, state of health, age, diving history, and basal metabolism.

Several acoustic techniques have been developed and applied to detect internal bubbles. The nonlinear acoustic incipient bubble detection technique was instrumented and used in these experiments. A brief description of the nonlinear ultrasonic propagation technique follows.

When an ultrasonic sinusoidal pressure wave propagates through a two-phase mixture such as bubbles in human tissue, the highly nonlinear gas compliance at the bubble interface causes point sources of primary wave distortion. The distortion of the primary sinusoidal wave produces harmonics which can be received and used as a very sensitive indicator of bubble presence.

The nonlinear ultrasonic propagation technique of bubble detection is not sensitive to blood flow rate and corpuscular movement, is applicable equally to moving and stationary bubbles, operates at low input energy levels, and is insensitive to subject motion with regard to harmonic generation.

A series of hyperbaric chamber dives were executed which had potential for producing bubbles within the human system and yet allowed decompression therapy prior to overt decompression sickness. The test subjects were instrumented with ultrasonic transducers and signal processing and recording equipment. Acoustic signals detected before, during, and after the dives were continuously recorded. These tests demonstrated that the nonlinear ultrasonic propagation technique can detect bubbles within both the venous and the capillary system, at a power level well below the recommended safe level, and well before diver awareness of symptoms.

This project was initiated by the Navy, and NOAA cooperated by supporting additional dives to collect more data for evaluation.

ARCTIC DIVING EXPEDITION: EQUIPMENT AND HUMAN PERFORMANCE EVALUATION

Principal investigator.—B. Andersen, Oceanautics, Inc.

Date.—November 22–December 22, 1972.

Location.—Resolute Bay, Northwest Territory, Canada.

Facilities used.—Sea floor work station *SUB-IGLOO.*

Basic to the development of resources in the Arctic is the capability of operating effectively on and under the ice. The national energy shortage implies even more activity in the polar regions in the years to come. Underlying the technology to sustain this is an understanding of the limitations of equipment and people.

The Arctic III expedition was conducted and sponsored by the MacInnis Foundation, a Toronto-based research organization and supported by the Donner Foundation, the U.S. Navy, National Oceanic and Atmospheric Administration, and several oil, chemical, engineering, and diving organizations. The Canadian Federal Department of Indian Affairs and Northern Development and the Canadian Defense Department provided logistic support. Documentation of the expedition was by the National Film Board of Canada and the National Geographic Society.

Objectives.—The general goal of the Arctic III expedition was a greater understanding of the undersea aspects of high-Arctic environment as they relate to exploration, preservation, and resource recovery in the polar regions. The prime method was the establishment of the manned undersea work station *SUB-IGLOO* (fig. 5) and evaluation of its utility and construction as a habitat for Arctic undersea research.

The human performance program was carried out as one of a number of scientific and engineering projects connected with the Arctic III expedition. The focus of the program was on the problems of diving in the extreme, cold-water Arctic environment, the capabilities and limitations placed on human performance by diver support equipment and apparel, and on performance of this equipment. Another objective of the human performance program was getting some measures of the thermal and physiological stress encountered by the divers working beneath the ice.

Procedure.—The data were collected by means of acoustic underwater telemetry systems, hardwire communication systems, and first-hand reporting. The investigator operated in a tent placed over a 4-ft hole made through 3 ft of ice. Data were collected on the following parameters: heart rate, body temperature, time in water, problems with equipment, and problems in assembling the underwater work station.

Results.—As with previous experiments it was found that single hose regulators tend to freeze in Arctic waters, but double hose regulators did not. Some problems were experienced with the closed circuit breathing apparatus. Generally speaking, the variable-volume dry diving suit was adequate protection in the 28.5°F water. The divers were able to function effectively under these conditions and successfully assembled the *SUB-IGLOO* work station in 40 ft of water on the sea floor. It proved essential that the exit and entry point for divers be inside a heated area, such as the tent provided. It was concluded that operations of this sort are entirely feasible when adequately planned.

Figure 5.—Underwater habitat *SUB-IGLOO* shown under the ice at Resolute Bay, Canada (courtesy of National Geographic Society).

Undersea Habitats and Laboratories

A list and status of available undersea habitats and laboratories, as of June 30, 1973, appear in table 2. Of these seven facilities only two, *HYDROLAB* and *PRINUL* (also known as *LA CHALUPA*), were utilized during FY 1973—to the extent shown in tables 3 and 4.

Table 2.—*Listing and status of undersea habitats and laboratories*

Name	Owner	Operational depth	Status (as of June 30, 1973)
		Ft	
EDALHAB	University of New Hampshire	45	Inactive; last used in Project FLARE, Fla., Jan.–Apr. 1972. Located ashore at Woods Hole.
HYDROLAB	Perry Foundation	50	Used in Bahama Banks research program during FY 1973. Located offshore at Freeport, Bahamas.
TEKTITE	General Electric	80	Inactive; last used in 1970 *TEKTITE II* project in Virgin Islands. Located ashore at Philadelphia Navy Yard.
PRINUL	Marine Resources Development Foundation.	100	First mission Nov. 1972 and used through June 1973. Located offshore at Mayaguez, Puerto Rico.
AEGIR	Makai Range	550	Inactive; last used in Hawaii in 1971 by the Navy. Located at Makai Range.
PORTALAB	University of Rhode Island	50	Inactive. Located at the University.
LAKELAB	University of Michigan	50	Tested in FY 1973 in Lake Michigan.

Table 3.—*Utilization of HYDROLAB facility*

Mo/yr	Mission No.	Subject	Water depth	Duration	Divers saturated	Man-days saturated
			Ft	*Days*		
7/72	1	Biology	45	7	4	28
8/72	2	Chemistry	45	7	4	28
8/72	3	Physiology and biology	45	7	3	21
9/72	4	Biology	45	7	4	28
9/72	5	Chemistry	45	4	3	12
10/72	6	Biology	45	6	4	24
10/72	7	Training	45	2	3	6
10/72	8	Biology	45	7	3	21
11/72	9	Biology	45	7	4	28
11/72	10	Psychology	45	2	3	6
12/72	11	Chemistry	45	6	4	24
12/72	12	Chemistry	45	7	3	21
1/73	13	Biology	45	7	3	21
1/73	14	Oil pollution	45	6	3	18
1/73	15	Sludge pollution	45	6	3	18
2/73	16	Biology	45	7	4	28
3/73	17	Chemistry	45	6	4	24
3/73	18	Fish study	45	6	3	18
4/73	19	Biology	45	5	4	20
4/73	20	Coral chemistry	45	6	3	18
5/73	21	Chemistry	45	6	4	24
5/73	22	Bioacoustics	45	6	3	18
5/73	23	Physiology	45	2	3	6
5/73	24	Oceanography and physiology	45	6	3	18
6/73	25	Biology	45	4	4	16
Totals				142	86	494

Table 4.—*Utilization of PRINUL facility*

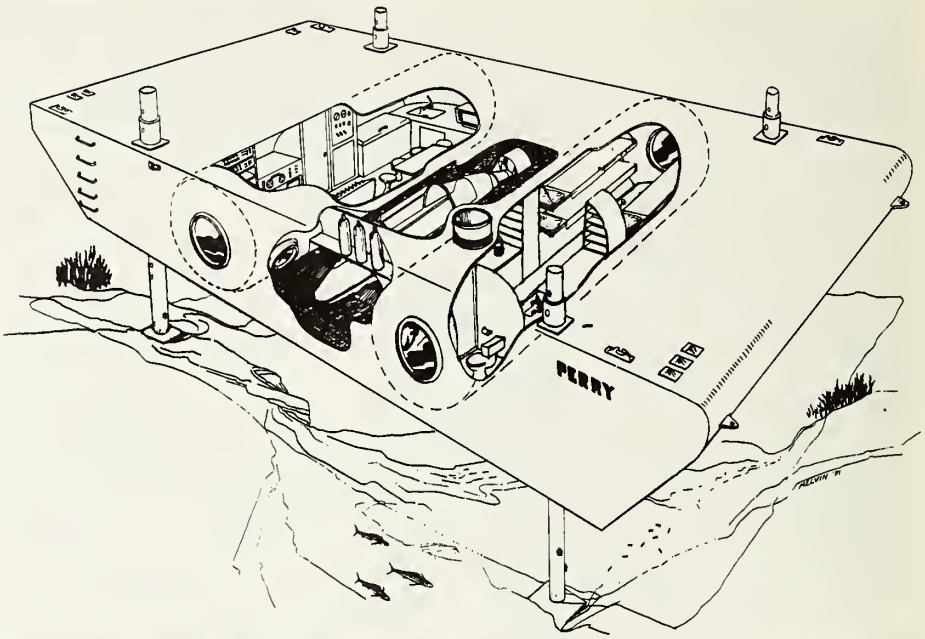
Mo/yr	Mission No.	Subject	Water depth	Duration	Divers saturated	Man-days saturated
			Ft	*Days*		
11/72	1	Benthic community structure and productivity.	60	14	4	56
12/72	2	Survey of nutrients and algal populations.	60	14	5	70
1/73	3	Fish food resource assessment	50	14	5	70
2/73	4	Behavior of reef fish	52	14	5	70
3/73	5	Coral physiology and survey coral species.	60	14	5	70
4/73	6	Diver physiology and marine biology	100	14	4	56
6/73	7	Conch studies	60	12	4	48
7/73 (FY 74)	8	Demonstrated embedding anchors by water jetting and siltation effects on corals.	60	14	5	70
8/73 (FY 74)	9	Metabolism of coral communities	65	14	5	70
Totals				124	42	580

Figure 6.—Habitat *HYDROLAB*.

HYDROLAB PROJECT

NOAA awarded a grant to the Perry Foundation, Riviera Beach, Fla., for the support of the *HYDROLAB* facility for use during FY 1973. *HYDROLAB* (fig. 6) was refurbished by Perry for improved operations. Its characteristics are:

Depth capability	100 ft
Size	8 ft diameter × 16 ft cylinder
Total volume	730 ft^3
Weight	134,000 lb
No. of divers accommodated	3–4



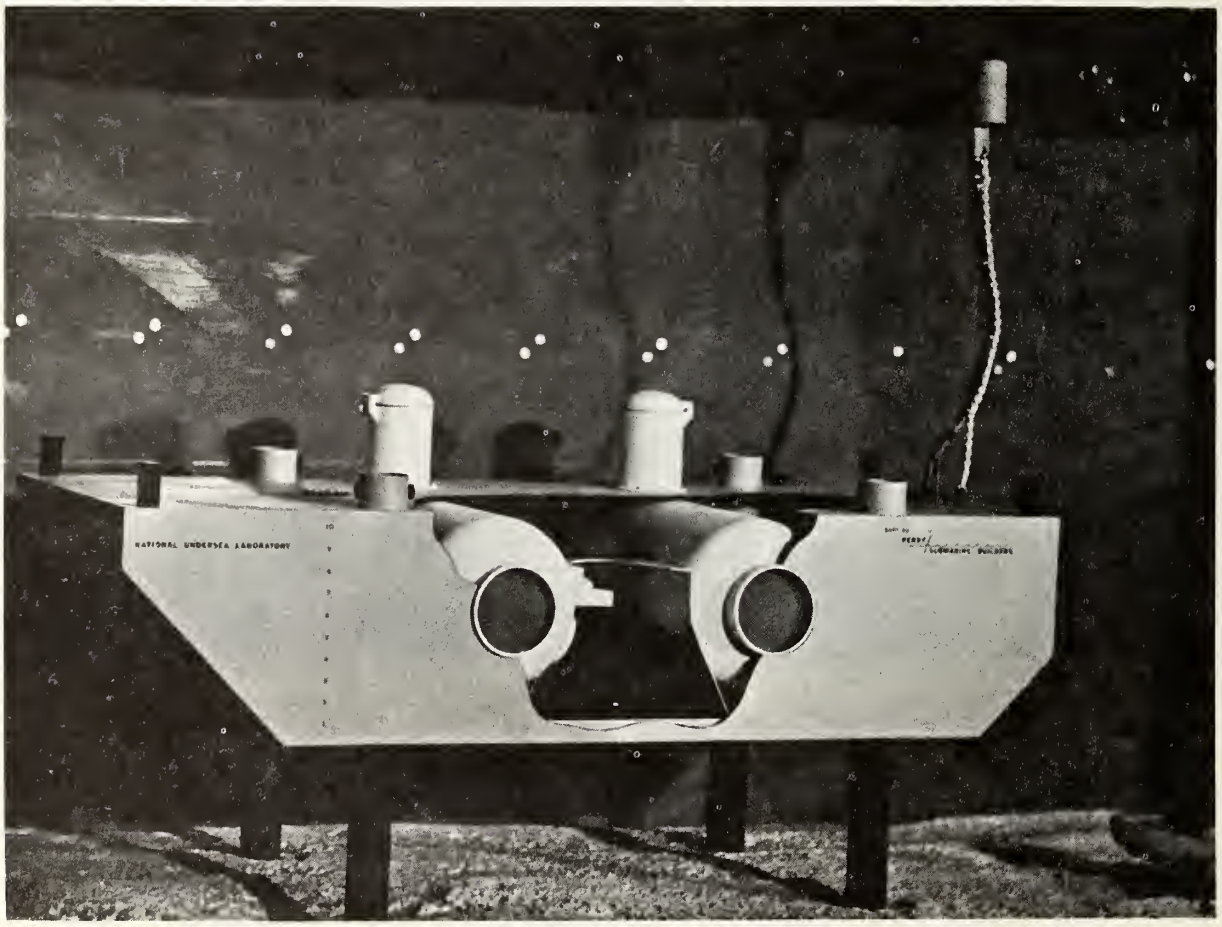


Figure 7.—Features of the PRINUL habitat *LA CHALUPA.*

The habitat is supported via an umbilical cable to an unmanned surface life support boat providing the following:

7.5 kW, 100 V AC by diesel-electric generator
Compressed air supply
Potable water supply
Habitat vent hose
CB radio link to shore
Emergency battery power, 3-day supply

The system is normally equipped to operate for 7 days with the life support boat, but under emergency conditions it can operate without the boat for 3 days.

The *HYDROLAB* facility (fig. 6) was used for 25 missions, saturating 85 scientist-divers for a total of 484 man-days, at a depth of 50 ft about 1 mile off Freeport, Grand Bahama Island. It will continue to be used in science projects during fiscal year 1974.

PRINUL PROJECT

NOAA supported the *PRINUL* project with a grant to the Marine Research and Development Foundation, thus directly supporting a total of nine man-missions (about 25 percent of the total).

The *PRINUL* facility (fig. 7), completed by Perry Oceanographics in September 1972 and tested offshore at Riviera Beach, Fla., was transported to Puerto Rico where it was used in its first mission in November 1972. It was deployed at several sites at depths from 50 to 100 ft within 10 miles of the southwest coast of Puerto Rico at Mayaguez and used for nine missions, saturating 42 scientist divers for a total of 580 man-days. Other significant diver statistics compiled during the nine missions are 1,624 hours in the water, 1,711 excursions from the habitat, and 57 minutes average excursion time.

The *PRINUL* system represents the trend from slow-movable underwater habitats to highly transportable underwater laboratories and combines several advancements, such as increased space for laboratory facilities, improved transportability for rapid emplacement and retrieval, capability for dry transfer of personnel from small submersibles, and computer facilities. *PRINUL's* characteristics are:

Depth capability ..... 100 ft
Size .. Two 8-ft diameter×19-ft cylinders with 9×19-ft sub port incorporated into a 20×48-ft barge
Volume of habitable space .... 3,150 ft^3
Weight ..... 267,000 lb
No. of divers accommodated 4
Tow speed ..... 5 knots

The system is supported via an umbilical cable to a 36-ft unmanned life support boat providing the following:

Two diesel-powered 20 kW electric generators providing 110 V AC
Compressed air supply
Potable water supply
Vent hose
CB radio link to shore

The system including the life support boat is normally equipped to operate for 14 days, but under emergency conditions can operate without the life support boat for 3 days.

The *PRINUL* system will continue to be used in science projects during FY 1974.

Research Submersibles

Table 5 lists and shows the status of 26 U.S.-owned and civilian-operated research submersibles capable of 600-ft depth or greater during the period July 1, 1972 to June 30, 1973. Sixteen of them were inactive or on lease overseas. The activities of the remaining 10 submersibles are outlined in table 6. For fiscal year 1973, MUS&T invoked a policy to lease only American Bureau of Shipping (ABS)-classed or Navy-certified submersibles for use on its projects. Of the 10 submersibles active in the U.S. during fiscal year 1973, only seven are so classed or certified.

During this period the MUS&T program utilized four submersibles, *DEEPSTAR 2000*, *NEKTON BETA*, *NEKTON GAMMA*, and *ALVIN* (figs. 8–11), for a total of 130 dives. Their characteristics are included in table 7, and the missions employing them are described under "Scientific Operations."

Table 8 lists the U.S. Navy submersibles used in FY 1973 and their characteristics. These submersibles were used mostly for test and evaluation and equipment and operator training.

Table 5.—*Status of U.S.-owned and civilian-operated submersibles, capable of 600-ft depth or greater, July 1, 1972 to June 30, 1973*

Name	Owner	Depth	Active	Certification			Remarks
				ABS	ABS pending	Navy	
		Ft					
ASHERAH	Techoceans	600	No	No	No	No	
TECHDIVER	International Underwater Contractors.	600	No	No	No	No	
SEA RANGER	Verne Enginering	600	Yes	No	No	No	Undergoing trials.
SUBMANAUT	Submarine Services	600	No	No	No	No	
PC–8B	Northern Offshore Limited	800	Yes	Yes		No	Overseas.
SHELF DIVER[1]	SECT[3]	800	Yes	Yes		No	Do.
GUPPY	Sun Shipbuilding and Drydock Company.	1,000	No	Yes		No	Tethered.
NEKTON ALPHA	General Oceanographics	1,000	No	No	No	No	
NEKTON BETA	do	1,000	Yes	Yes		No	
NEKTON GAMMA	do	1,000	Yes	Yes		No	
SNOOPER	Undersea Graphics Inc.	1,000	Yes	No	No	No	
SEA LINK[1]	Smithsonian Institution	1,000	Yes	Yes		No	
BENTHOS V	Garrison Diving and Salvage Co.	1,000	No	No	No	No	
SEA RAY	Submarine Research and Development Company.	1,000	No	No	No	No	
PC–9	Taylor Diving and Salvage Co.	1,200	Yes	Yes		No	Overseas.
STAR II	General Dynamics	1,200	Yes	No	No	No	
OPSUB	Ocean Systems	1,200	No	No	Yes	No	Overseas, tethered.
DEEP DIVER[1]	Perry Oceanographics	[2]1,250	No	No	No	No	
DEEPSTAR 2000	Westinghouse	2,000	Yes	Yes		No	
STAR III	Scripps Institution of Oceanography.	2,000	No	No	No	No	
BEAVER MK IV[1]	International Underwater Contractors.	2,700	Yes	Yes		Yes	Ready, spring 1973.
DEEPSTAR 4000	Westinghouse	4,000	No	No		Yes	
DOWB	Santa Barbara City College	6,000	No	No	No	No	
ALVIN	U.S. Navy	6,000	Yes	No	No	Yes	12,000 ft in summer 1973.
DEEP QUEST	Lockheed	8,000	Yes	No	No	Yes	
ALUMINAUT	Reynolds International	15,000	No	No	No	No	

[1] Diver lockout.
[2] Now limited to 100 ft.
[3] Service des Equipements de Champs de Tir.

Table 6.—*Activities of U.S. civilian-operated submersibles, July 1, 1972 to June 30, 1973*

Submersible	Date	Mission[1]	Location	No. of dives	Dive days	Depth Ft
SEA RANGER		Sea trials	Lake Michigan			200
NEKTON BETA	10/72	Living reef studies (NOAA).	British Honduras	84	14	to 1,000
Do	6/73	Oil seepage	California	10	3	85–240
NEKTON GAMMA	1–12/72	(Varied)	Gulf of California; Lake Michigan.	252		to 1,015
Do	1/73	Testing	California	1	1	20
Do	5/73	Pipeline inspection	do	54	9	20–220
Do	6/73	Lobster survey (NOAA).	Veatch Canyon	27	10	250–950
SNOOPER	7/72	Bottom sampling	Palos Verdes, Calif.	3	1	200
Do	8/72	Demonstration	Redondo Canyon, Calif.	17	4	to 600
Do	5/73	Outfall inspection	Palos Verdes, Calif.	3	1	200
SEA LINK	5/73–6/73	Scientific & training	Florida	32	26	40–350
STAR II		Coral harvest	Hawaii	41	40	to 1,200
DEEPSTAR 2000	7/72	Sediment transport & ecology (NOAA).	New York Bight	13	10	to 1,365
BEAVER MK IV	5/73	Test & evaluation	City Island, N.Y.	6	3	16–25
Do	do	do	Block Island, R.I.	2	1	35–70
Do	do	Surveying test cable	do	1	1	120
Do	6/73	Surveying & burying test cable.	do	4	4	120
BEAVER MK IV	6/73	Surveying trans-Atlantic cable.	Block Island, R.I.	2	2	150
ALVIN	7/20/72	Glacial till	Mayo Swell	1	1	870
Do	7/21/72	do	Peck Ridge	1	1	410
Do	7/22–23/72	Bedrock samples	Fundy fault trend	2	2	315
Do	7/24/72	do	East of Cashes Ledge	1	1	410
Do	7/25/72	do	Cashes Ledge, northern area.	1	1	390
Do	7/26/72	do	Cashes Ledge, southern area.	1	1	290
Do	7/27/72	Glacial till	Rodgers Swell	1	1	640
Do	8/24/72	Bedrock seen	Cashes Ledge, central area.	1	1	380
Do	8/25/72	do	do	1	1	415
Do	8/26–27/72	Bedrock samples	do	2	2	400
Do	8/29/72	do	do	1	1	450
Do	9/72	Ecology & sediment transport (NOAA).	Hudson Canyon	6	6	4,700
DEEP QUEST	7/72	Geology, biology	Southern California	4	4	4,212–6,711
Do	do	ARPA[2] experiments	do	2	2	60
Do	8/72	Bottom sediment research.	Southern California	3	3	4,020–4,060
Do	do	ARPA[2] experiments	do	2	2	65
Do	10/72	System testing	do	2	2	2,400–4,035

[1] Missions supported by NOAA are so noted.
[2] Advanced Research Projects Agency.

Table 7.—*Characteristics of civilian-operated U.S. submersibles*

Name	Maximum operational depth	Submerged speed		Endurance submerged	Life support Normal
		Cruising	Maximum		
	Ft	*Knots*	*Knots*	*Man-hr*	*hr*
ASHERAH	600	1	3.5	12	48
SEA RANGER	600	2	4	30	60
SUBMANAUT	600	5	10	100	48
TECHDIVER	600	2	4	4	12
PC–8	800	1	3	8	48
SHELF DIVER	800	2	3	6	40
BENTHOS V	1,000	2	3	4	96
GUPPY	1,000	3	3	56	56
NEKTON ALPHA	1,000	2	3.5	6	10
NEKTON BETA and GAMMA	1,000	2	3.5	6	48
SEA LINK	1,000	1	2	8	72
SEA RAY	1,000	2	6	5	16
SNOOPER	1,000	1	3	6	10
PC–9	1,200	—	4	12	72
STAR II	1,200	1	3	8	48
OPSUB	1,200	2	—	—	24
DEEP DIVER	[1] 1,250	2	3	4	40
BEAVER IV	2,700	2.5	5	12	120
DEEPSTAR 2000	2,000	1	3	8	36
STAR III	2,000	2	3.5	6	120
DEEPSTAR 4000	4,000	1	3	8	12
DOWB	6,500	0.5	2.5	26	195
DEEP QUEST	8,000	2	4	18	192
ALVIN	[2] 12,000	1	2	8	72
ALUMINAUT	15,000	1.5	3.5	24	336

[1] Now limited to 100 ft. [2] Titanium sphere, otherwise 7,200.

Table 8.— *Characteristics of U.S. Navy-operated submersibles* [1]

Name	Maximum operational depth	Submerged speed		Endurance submerged	Life support Normal
		Cruising	Maximum		
	Ft	*Knots*	*Knots*	*Hr*	*Man-hr*
MAKAKAI	600	1.5	3	6	24
NEMO	600	1	1	8	8
DEEP VIEW	[2] 1,500	1.5	5	6	48
DSRV 1 & 2	5,000	3	5	12	—
SEA CLIFF & TURTLE	6,500	1	2.5	8	100
TRIESTE II	20,000	2	3	12	72

[1] Other Navy-owned and -operated undersea vehicles are *NR-1* and *DOLPHIN*. *NR-1* is a nuclear powered, ocean research and engineering vehicle. *DOLPHIN* is used as an ASW research submarine and is not considered readily applicable to civilian research.
[2] Currently Navy certified to 100 ft.

Table 7.— *continued*

Life support Maximum	Crew	Observers	Payload	Length	Weight in air	View ports	Manipulators
Man-hr	*No.*	*No.*	*Lb*	*Ft*	*Lb*	*No.*	*No.*
48	1	1	200	17	—	6	0
120	1	3	2,200	17	19,000	11	2
48	2	6	6,000	44	108,000	8	0
18	1	1	200	22	5,500	17	0
48	1	1	200	19	11,000	9	1
60	1	3	1,200	23	17,000	25	0
96	1	1	400	18	4,200	6	1
56	1	1	—	11	5,800	3	1
48	1	1	50	15	4,500	20	1
48	1	1	350	15	4,500	17	1
72	1	4	700	24	17,900	4	0
32	1	1	350	20	8,429	8	1
32	1	1	200	14.5	4,900	10	1
72	1	2	2,000	25	21,000	21	—
48	1	1	500	17	10,000	6	0
26	1	1	—	18	10,400	13	0
60	1	3	1,200	23	16,550	20	0
144	2	2	1,337	24	34,000	9	2
108	1	2	500	20	17,500	2	1
120	1	1	970	25	20,000	5	1
48	1	2	500	18	18,000	3	1
195	2	1	1,050	17	20,000	2	1
204	2	3	7,000	40	115,000	2	2
72	1	2	1,500	23	32,000	3	1
502	3	4	4,000	51	146,000	4	2

Table 8.— *continued*

Life support Maximum	Crew	Observers	Payload	Length	Weight in air	View ports	Manipulators
Man-hr	*No.*	*No.*	*Lb*	*Ft*	*Lb*	*No.*	*No.*
36	1	1	1,200	19	10,600	1	—
16	1	1	—	6	—	1	0
48	1	1	500	16	12,000	1	0
—	3	24	4,300	50	73,900	3	0
107	2	1	700	26	48,000	5	2
108	1	2	2,000	67	100,000	1	2

Figure 8.—Submersible *DEEPSTAR 2000.*

Figure 9.—Submersible *NEKTON BETA* on location.

Figure 10.—Submersible *NEKTON GAMMA.*

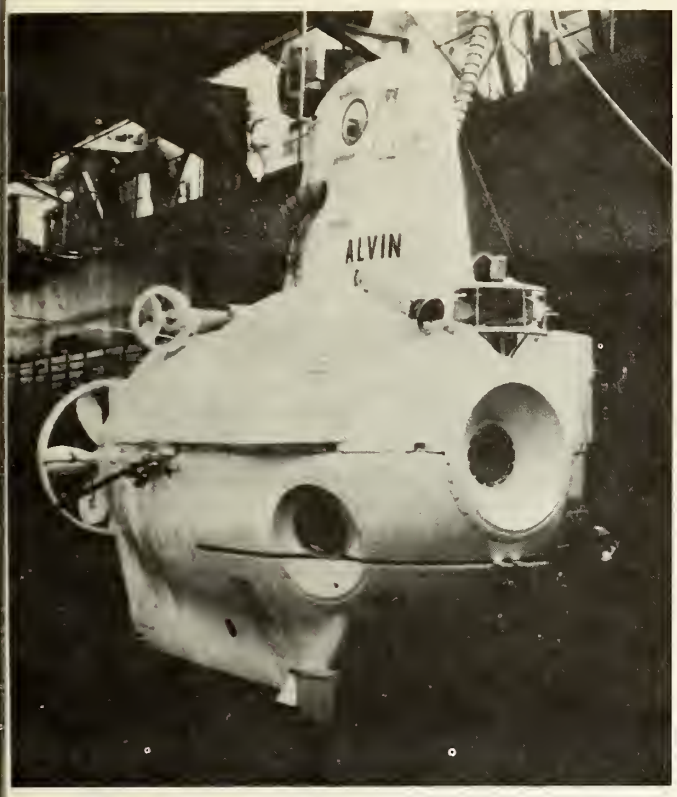
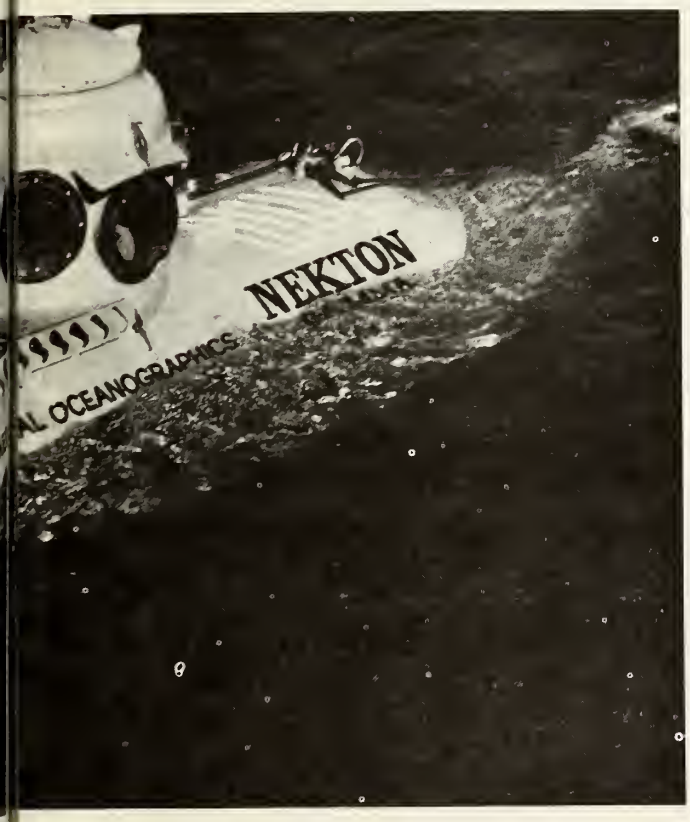


Figure 11.—Submersible *ALVIN*.



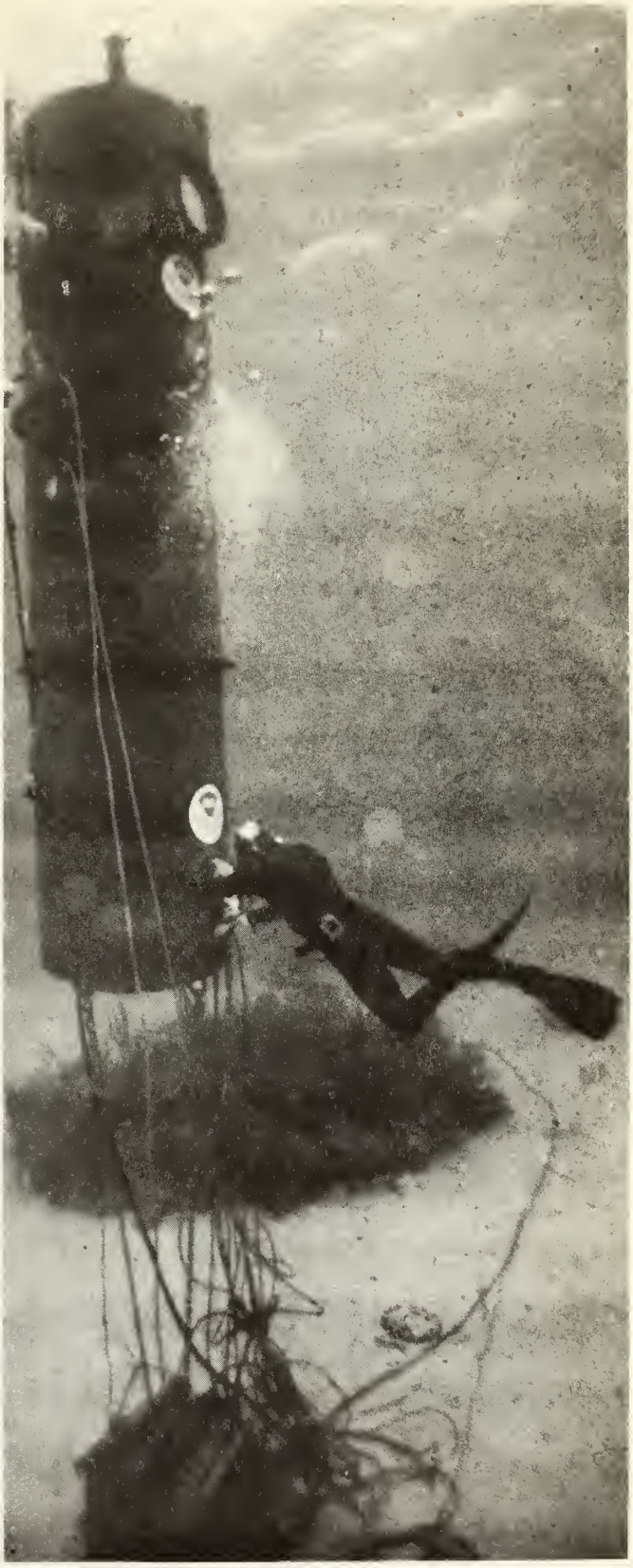


Figure 12.—Undersea Instrumentation Chamber (USIC).

Instrumentation

ADAPTATION OF SCIENTIFIC INSTRUMENTS FOR USE ON THE SEA BED

The University of Miami received a NOAA grant to adapt two instruments, a spectroradiometer and a NASA mass spectrometer, for underwater use on the seabed in support of scientific missions from *HYDROLAB*.

The spectroradiometer will be used to measure absorption of light energy in watts per square centimeter over the light spectrum received underwater. Its sensor was repackaged into a 12-in diameter and 14-in long cylindrical structure capable of withstanding 150 psi pressure for operations to 300 ft. The controls were rearranged to operate remotely through the lid of the enclosure. The modified system has operated successfully in the laboratory. Field tests are scheduled for *HYDROLAB* in FY 1974.

A compact NASA mass spectrometer, 10×11×11 in, weighing about 28 lb, is being adapted for underwater research. It is capable of simultaneously monitoring 12 gases from mass 3 to mass 11. A major modification involved developing an inlet system for monitoring streaming water. The system will be repackaged into a housing capable of withstanding 150 psi pressure for operations to 300 ft. Work on this spectrometer will be completed in FY 1974.

UNDERSEA INSTRUMENTATION CHAMBER

The Undersea Instrumentation Chamber (USIC) (fig. 12) is an unstiffened steel cylindrical structure 42 in. in diameter and 15 ft long. The unit contains two compartments; one for housing the scientific instrumentation and the other for an entry port. USIC is deployed underwater in the upright position, moored on the lower end like an underwater buoy. The system enables instrumentation to be used in an ambient air environment for measuring and recording in situ from seabed instrumentation located inside and outside USIC. The system protects its internal instrumentation from hostile surface conditions and enables divers to have access to the instruments for calibration, data collection, and servicing.

The USIC system was deployed on the ocean bottom near the *HYDROLAB* in the Bahamas to monitor and measure the effects of sewage on the benthic coral communities. This mission is described under "Scientific Operations."

NUCLEAR ACTIVATION ANALYSIS

From October 1972 through FY 1973, several meetings among the Geological Survey, Atomic Energy Commission, National Aeronautics and Space Administration, and National Oceanic and Atmospheric Administration were held to review the technical characteristics and applicability of neutron activation analysis techniques for undersea detection of heavy metal pollutants, minerals, oil seepage, and radioactive materials in the coastal zone and deeper waters. Preliminary investigations by NOAA, AEC, and the Coast Guard have been conducted with californium 252 as the continuous neutron excitation source, sodium iodide and germanium-lithium detectors, amplifiers, signal processors, analog-digital converter, and multichannel analyzer and recorder. In previous missions this equipment has been packaged and attached for use from a submersible.

The meetings have recognized the potential benefits from continually improving and applying these techniques and will be continued in fiscal year 1974 to plan a system utilizing an improved equipment package.

Technology Transfer

During FY 1973 the MUS&T staff kept abreast of the latest undersea technology developments in the Navy and industry by attending briefings, review meetings, and symposia, reviewing reports and proposals, and conducting surveys pertaining to submersible systems and underwater laboratories and their subsystems and ancillary support systems, diving equipment, physiology, instrumentation, and undersea power sources. The MUS&T staff attended the monthly briefings in the Navy's Deep Submergence Systems Program Coordinator's office and supported an informal survey of diving equipment carried out by the National Bureau of Standards.

Although considerable knowledge on undersea systems and equipment developed by the Navy has been obtained, utilization of the technology has been limited by the small number and modest scale of MUS&T projects conducted in this period. Nevertheless, part of the technology program is to work closely with the Navy on behalf of the civilian agencies' undersea requirements and needs. Systems and equipment already developed by the Navy and industry will be used or adapted whenever possible.

Scientific Operations

A variety of scientific operations were conducted off the U.S. east coast, the Bahamas, Puerto Rico, and British Honduras (fig. 13). Several research submersibles and two habitats were used, and the participating personnel came from academia, research institutions, industry, and various interested Federal and State agencies. Although the MUS&T office had the lead management or coordination role in these programs, funding came also from other NOAA groups and such Federal agencies as the National Science Foundation, EPA, AEC, and the Navy. Table 9 is an outline summary of the missions.

These missions were selected to support national and regional goals in marine science and resource evaluation and development. The knowledge gained from them will be a basis for longer range and more extensive marine endeavors and the solution of problems accruing from coastal zone ocean-land interactions. The results and data published in this report are summaries which are and will be complemented by more extensive publication, such as reports or articles in professional journals. Mission reports and results also may be obtained through the MUS&T office of NOAA.

Figure 13.—MUS&T projects, fiscal year 1973.

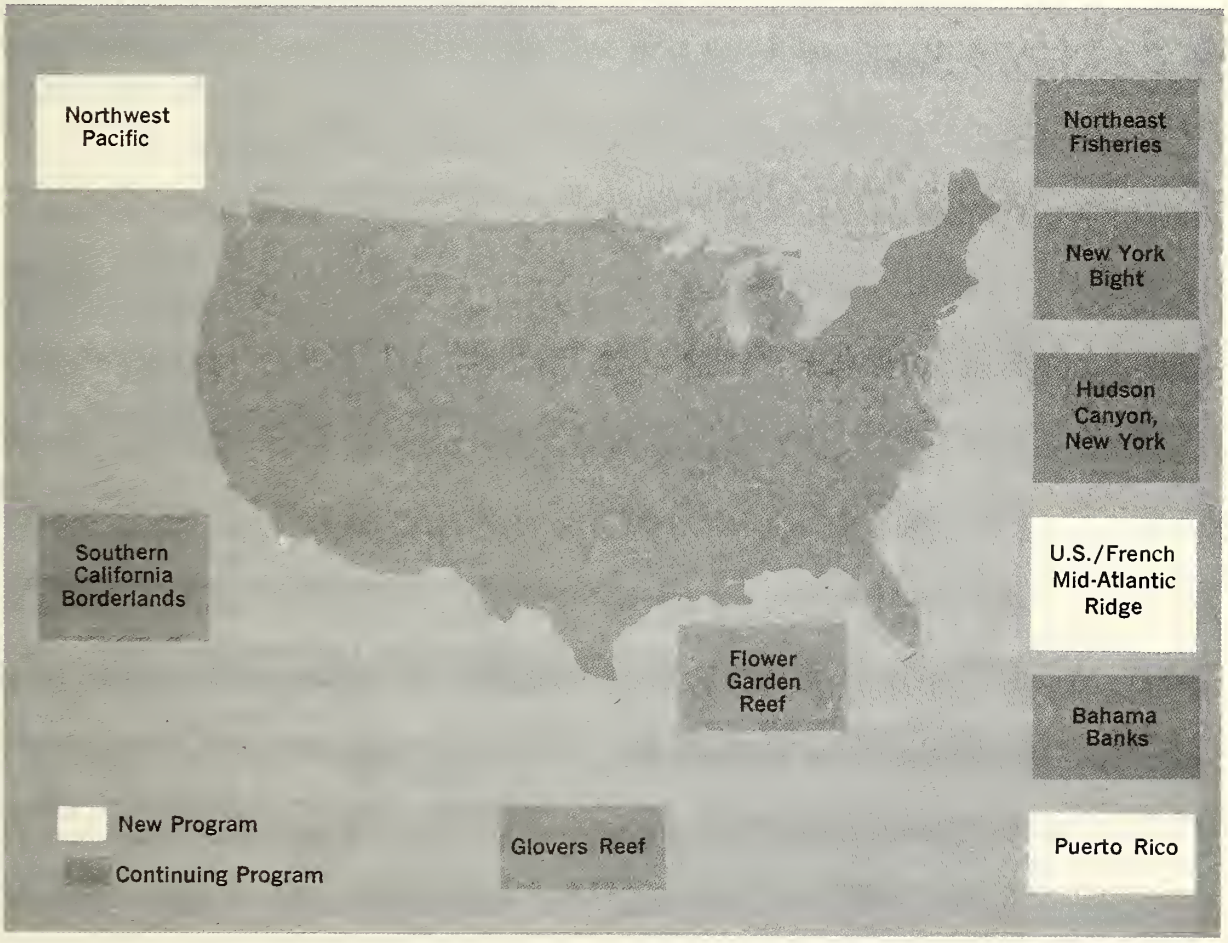


Table 9.—*Summary of science missions, MUS&T office, fiscal year 1973*

Mission	Date	Subject
Northeast Coast Fisheries	June 5–22, '73	Ecology of deep water lobsters.
Do	Sept. 22–Oct. 18, '72	Herring spawning and early life history.
Hudson Canyon	Sept. 6–15, '72	Bottom current conditions.
Bahama Banks:		
1	July 10–18, '72	Habitat internal environment study.
2	July 11–16, '72	General marine and environmental research.
5	Aug. 31–Sept. 5, '72	Standing stock distribution.
9	Nov. 15–21, '72	Coral studies.
12	Jan. 3–8, '73	Fish behavior.
16	Feb. 4–9, '73	Seasonal change in coral.
22	Apr. 1–6, '73	Do.
27	June 3–8, '73	Do.
3	Aug. 1–8, '72	Shallow reef environment.
7	Oct. 1–7, '72	Do.
10	Dec. 1–7, '72	Do.
18	Mar. 1–7, '73	Do.
24	May 1–7, '73	Do.
4	Sept. 11–18, '72	Coral reef ecosystem.
8	Aug. 27–Nov., '72	Do.
26	May 26–June 1, '73	Do.
6	Sept. 11–15, '72	Feeding behavior in marine invertebrates.
11	Dec. 12–19, '72	Oxygen in seawater.
13	Jan. 3–8, '73	Adjacent flora and dependent fish.
14	Jan. 16–22, '73	Behavior and effects of oil.
15	Jan. 26–Feb. 1, '73	Treated sewage sludge.
17	Feb. 9–15, '73	Cosmic ray muon and star study.
20	Mar. 21–23, '73	Do.
19	Mar. 13–20, '73	Cohabiting fishes and species interactions.
21	Mar. 28–Apr. 22, '73	Serological studies.
23	Apr. 2–22, '73	Light and pigment in coral.
25	May 16–21, '73	Acoustical behavior of reef fishes.
British Honduras:		
[1] 2	Oct. 10–30, '72	Processes of living reefs.
PRINUL[2]:		
1	Nov. 18–Dec. 1, '72	Mapping, oxygen metabolism, community types, physical environment, animal behavior.
2	Dec. 18–31, '72	Benthic algae.
3	Jan. '73	Underwater microscope.
4a	Feb. '73	Feeding and space study of fish.
4b	do	Behavioral mechanisms of cleaning symbiosis.
5	Apr. 24–May 4, '73	Ocean floor biological survey; radiation physics.

[1] First mission described in MUS&T report, 1972.
[2] Puerto Rican International Underwater Laboratory.

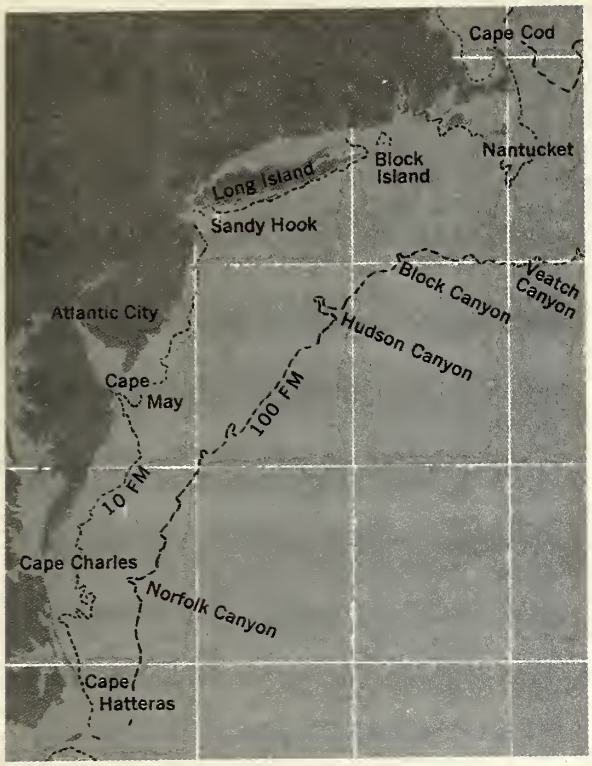


Figure 14.—Mid-Atlantic Bight showing undersea canyon dive sites.

UNITED STATES NORTHEAST COAST FISHERIES SURVEYS

NOAA's Northeast Fisheries Center undertook two scientific underwater projects in the New England coastal ocean areas during the autumn of 1972 and spring of 1973.

Project 1: Ecology of Deep Water Lobsters

Principal investigators.—R. Cooper and J. Uzmann, NOAA, Northeast Fisheries Center.

Senior associate investigators.—K. Pecci, National Marine Fisheries Service (NMFS); W. Whipple, Prelude Lobster Corporation.

Location.—Veatch and Norfolk Canyons (fig. 14).

Dates.—June 5–22, 1973.

Facilities used.—*NEKTON GAMMA* submersible and support ship *G. W. PIERCE.*

Objectives:

Develop methodology for a rapid, economical inventory of offshore stocks of lobster, shrimp, and crab. An economical method for obtaining basic quantitative distribution data for several commercially fished invertebrate species (lobster, shrimp, crab) is required to annually assess these resources for State and Federal management decisions. A minimum requirement is an annual measure of abundance and geographic distribution, but as yet there is no economical way of getting this information.

Calibrate several commonly used surface-oriented sampling techniques for assessing living resources.

Define the ecology, population structure, and trap-related behavior of the offshore lobster. Included in this objective is a quantitative assessment of "ghost pots" and their potential effect on the lobster and crab resources.

Results.—The project achieved the following:

A data base on abundance and ecology of 40 species of bottom-living fauna. This data base will be used to calibrate several surface-oriented survey techniques commonly used by fishery research biologists (otter trawl, photographs, sled, grabs, and dredge).

An assessment of the abundance and potential harm of "ghost traps" to the lobster resource.

An assessment of the population structure of lobsters with depth and habitat type, considering specifically:

- Juvenile abundance
- Spawning/shedding/mating
- Food availability
- Suitable shelter to minimize predation on juveniles and soft lobsters.

An assessment of the potential harm of foreign and domestic otter trawl activities on the bottom substrate and its fauna.

Some important initial observations are:

Despite a scarcity of shelter in the area around Veatch Canyon (depth to 1,000 ft) numerous lobsters, crabs, and fish were observed. The few isolated boulders and objects on the bottom usually had a number of lobsters, crabs, and fish associated with them.

No juvenile-sized lobsters (less than 2 years old) were observed in the Veatch Canyon area. However, a submersible dive in the Norfolk Canyon area observed lobsters that were considered young of the year.

Large tilefish *(Lopholatilus chamaeleonticeps)* estimated to weigh up to 100 lb each (the largest ever caught was 40 lb) were observed in Veatch Canyon

in and around clay tunnels (excavations in the canyon walls).

Lobsters were widely distributed over the area; many live in bowl-shaped excavations in the flat bottom and some in clay burrows.

Many of the communities of bottom-dwelling invertebrates seem to be distributed in belts parallel to the depth contours.

Two of the techniques used for censusing the larger bottom-living animals seem to be feasible methods for routine sampling of large areas of the sea bottom.

Dense populations of lobster, jumbo shrimp, jonah crab, galatheid crab, tilefish, cusk eel, and rosefish were discovered in pueblo-like communities at 400–600-ft depths in Veatch Canyon. It is hypothesized that this pueblo area represents the home ground of the deep water lobsters from which their migrations emanate.

Project 2: Spawning and Early Life History of Herring

Principal investigators.—R. Cooper, H. Boyar, and J. Uzmann, NOAA, Northeast Fisheries Center.

Location.—Jeffreys Ledge, Gulf of Maine (fig. 15).

Dates.—September 22 through October 18, 1972.

Facilities used.—Two trawlers; one for herring egg dredging and the other as a scuba diver support boat (the *M. V. PAULA* and the *M. V. BARBARA L.*). Scuba divers operated to 45-m (140 ft) depths.

Objectives:

An understanding of the spawning and early life history of herring (*Clupea harengus harengus* L.) on Jeffreys Ledge, and the first attempt to investigate details on spawning and early life history of herring in a specific locality in the coastal waters of the Gulf of Maine.

An assessment of the ecological factors that determine year class strength and of the relative value of a major spawning site to the maintenance of the herring fishery.

Results and comments.—In recent years, the fishing industry of the United States has intensified its efforts to harvest the Atlantic sea herring. At the same time other nations have come to the waters of the northwest Atlantic with the same goal in mind. The herring is commercially important as food for humans and lower animals, lobster bait, fish meal, pearl essence, and oil extract. The average yearly amount (mostly adults) landed from Georges Bank for 1968 through 1971 was 257,000 metric tons. In the Gulf of Maine the average yearly catch (adults) for the same period was 42,000 metric tons.

Fishermen from the United States have been concerned with increasing their catches of juvenile herring, and fishermen from other nations with increasing their catches of adult herring. Within the last 5 years there has been a concerted effort by some U.S. fishermen to harvest adult herring also. An area which they have fished extensively is Jeffreys Ledge. Vessels from other nations are now also fishing this area.

In 1972 approximately 9,026 metric tons of herring (primarily adults) were obtained by U.S. fishermen from Jeffreys Ledge and contiguous waters. The 1972 tonnage obtained by other vessels from this area is not yet documented. Various National Marine Fisheries Service (NMFS) studies indicate that the stock of herring from Jeffreys Ledge contributes substantially to the fishery for herring in the inshore waters of parts of the Gulf of Maine. Additional proof is that, although there is no documentation of a large juvenile fishery on Jeffreys, herring spawn in these waters.

The fall 1972 investigation on Jeffreys Ledge was a preliminary study of the spawning and early life history of the herring. The spawning area including substrate type and physical characteristics of the water mass, time of spawning, and dispersal of the larvae was documented. In situ observations on spawning, predation on the eggs, and hatching were not possible because of the depth limitations on the scuba team.

Mortality processes acting on this early life history stage may affect recruitment levels through (1) overthickness (layer depth) of eggs on a specific bed with suffocation of the bottom layer of eggs, (2) predation of the eggs, (3) unsuitable substrate for egg adhesion, (4) unfavorable physical and chemical conditions of the water mass, (5) disturbance of the egg bed through fishing operations (i.e., trawling), and (6) low number of viable eggs because of insufficient sperm cover. Direct measurements on these factors via diver-scientists are planned for the fall of 1973, using surface-supplied air and umbilical diving techniques.

Trawl collections of prespawning, spawning, and postspawning herring indicated that the 1967, 1968, and 1969 year classes were dominant in the samples. Of these, the majority of fish from the 1969 year class would not spawn until 1973. Fish of age groups 4 to 8+ spawned at least at two sites on Jeffreys Ledge. The site where most of the fish congregated was approximately 42°46′N, 70°11′W. The second spawning site was approximately

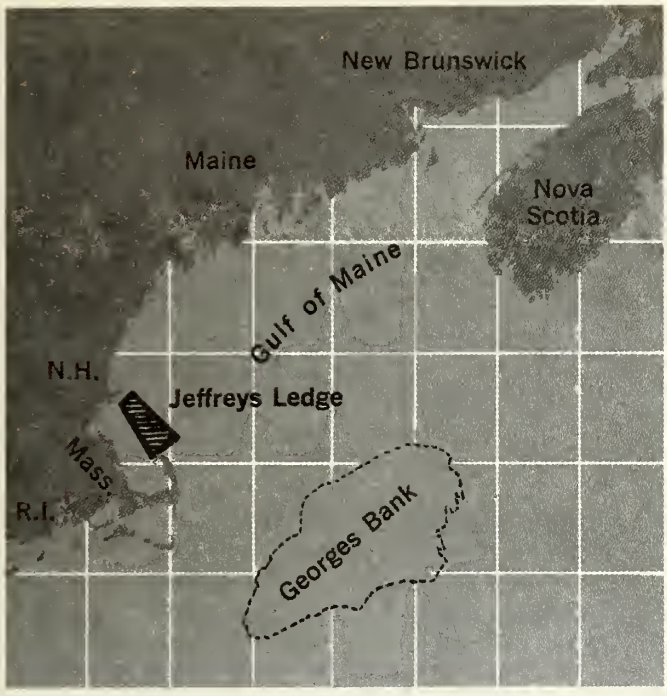


Figure 15.—Jeffreys Ledge (shaded area) dive site.

42°40′N, 72°25′W. Although it has been proposed that herring school according to size, NMFS catches indicated that herring of varying sizes of an age group and several age groups were schooled. There was no indication that older fish or the large fish of an age group spawn first, move off the spawning ground, and are replaced by the smaller fish of the age groups.

Larval herring indicated that spawning on Jeffreys Ledge began in early September. The peak of spawning was during the first 3 weeks of October; most of the fish had dropped their eggs by October 20. Newly hatched larvae, 6–8 mm long, were relatively abundant on October 18, suggesting that spawning had occurred 1 to 2 weeks earlier. NMFS results are similar to those reported for Georges Bank: the bulk of spawning is completed in approximately 10 days.

The herring on Jeffreys Ledge spawned in waters of 53–59 meters. The temperature of the bottom during spawning ranged between 7°C and 8.5°C. In the 10 dredge-sets in which eggs were obtained, the bottom was primarily a gravel-rock-boulder substrate. Eggs were, however, found on a few sand-rock and clay-rock substrates. The fact that eggs were not obtained at many stations does not prove that they were not there.

There is a question about the efficiency of the Naturalist Dredge to adequately sample egg beds. An earlier experimenter used scuba techniques in a survey of herring spawning in the Bay of Chaleur and found eggs attached to seaweeds and fishing gear, but not on bare sand, gravel, or rock. It appears that herring in different parts of the Atlantic Ocean spawn over various types of substrate, but in most cases prefer a gravel-rock bottom.

The presence of yolk-sac larvae close to the center of fishing activity (purse seiners) and close to the area where eggs were obtained from the stomachs of codfish taken by commercial fishermen add credence to the conclusion that there were at least two spawning sites on Jeffreys Ledge. The length frequencies and mean lengths of larvae obtained prior to October 10 further indicate that spawning began in September. The large larvae (20–28 mm) obtained on Jeffreys Ledge prior to the peak of spawning may have come from waters other than Jeffreys Ledge. These larvae could have drifted down from either St. Mary's Bay, Nova Scotia, where spring spawning occurs, or from eastern Gulf of Maine where spawning begins earlier than in the western Gulf of Maine.

Immediately after the peak of spawning, NMFS began sampling the larval herring. The mean lengths of larvae on each transect increased with increasing distance from the spawning bed. Only on two transects did the number of larvae increase with increasing distance from the egg bed. There is a definite indication that most of the larvae are transported inshore by the current.

Jeffreys Ledge is considered a major source of herring larvae for the coastal waters of the western Gulf of Maine and a major contributor to the larvae found there during the spring. The larvae would appear to move with the spring currents that are directed shoreward in compensation for river outflows.

In general, it appears that the progeny of the herring that spawn on Jeffreys Ledge contribute to the population of larvae found along the coastal waters of the western Gulf of Maine. These larvae eventually grow to become juvenile herring exploited by coastal fishermen. The relative importance of spawning on Jeffreys to their progeny of juvenile herring in the coastal waters is still unknown, as is the contribution of these juveniles to the future adult fishery.

HUDSON CANYON INVESTIGATIONS

The Hudson Canyon, 220 km southeast of New York City, is the most pronounced of the east coast canyons, cutting from 200 to 800 m into the continental slope and extending approximately 370 km from the shelf edge to the deep sea (fig. 16). Its axial slope is about 23 m/km to a depth of 800 m, increasing to about 30 m/km out to 2,000 m. Its overall appearance is that of a relatively broad (7–9 km wide), well-incised canyon which has been blanketed with fine-grained sediments throughout most of its length. Only in the canyon head area does erosion appear. Within the central canyon (at depths of 400–1,000 m) ridges of semiconsolidated silty clay trending both parallel and perpendicular to the axis rise as much as 70 m above the canyon floor. Indications are that some of the ridges crossing the canyon serve to restrict the movement of bottom water up and down the canyon.

This study was undertaken to investigate the bottom current conditions in the Hudson Canyon, to relate these conditions to both the mass physical properties and flux of the sediment, and to determine the influence of the currents on the benthic fauna within the canyon.

Principal investigator.—G. Keller, NOAA, Atlantic Oceanographic and Meteorological Laboratories (AOML).

Associate investigators.—Eight scientists and technicians from Lehigh University, Woods Hole Oceanographic Institution, AOML, and Georgia Institute of Technology.

Location.—Hudson Canyon (fig. 16).

Dates.—Sept. 6–15, 1972.

Facilities used.—The research submersible *ALVIN* (fig. 17) and the research support vessels *LULU* and *ANNANDALE*.

Objectives.—The experiment was arranged to survey and sample a series of sites in the canyon complementary to the areas studied during June 1972 and reported on in the 1972 MUS&T report. The objectives were similar, as follows:

Investigation of the dynamic processes active in submarine canyons.

Studies of the sedimentary processes within the canyon by measuring bottom current and sediment transport and by photographically recording the dimensions and lineation of bottom features such as ripples and scour pockets.

In-place surface sediment density measurements.

Physical and chemical analysis of sediment cores.

Measurements of bottom currents and suspended sediment concentrations.

Study of benthic biota and their concentration and influence on sediment stability.

Stratigraphic sampling of the canyon walls in order to develop the geological history of the canyon.

Geophysical studies from surface vessels to determine the structure and overall depositional environment of the canyon.

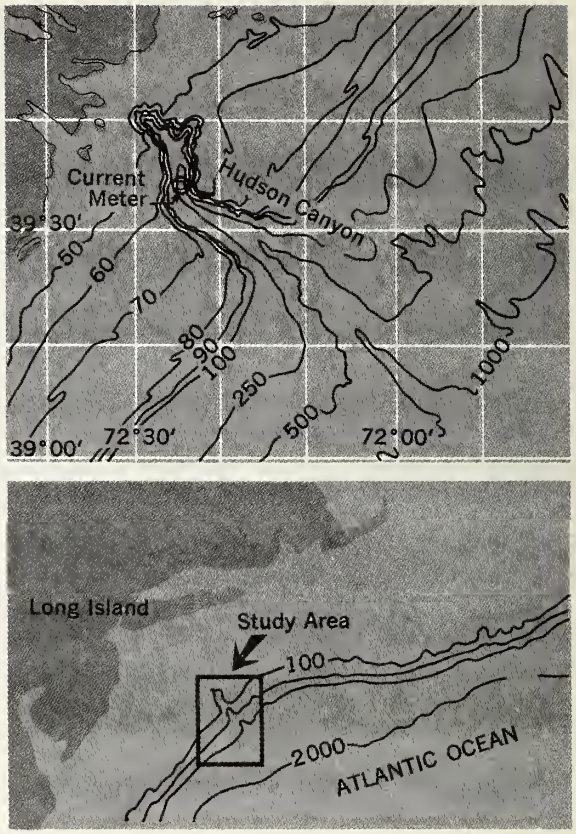


Figure 16.—Hudson Canyon dive site.

Results:

Much of the study was from the submersible *ALVIN* during a series of six dives in September 1972. Basic observations during the dives consisted of measurements of bottom currents with a Savonius type meter held 12 cm above the canyon floor, collection of suspended sediments, core and grab sampling of the bottom sediment, and almost continuous photographic coverage of the dive sites. The dive sites were located from the canyon head out to depths of 1,826 m, and the average time on the bottom was 4 hours per dive. In addition to observations from the submersible, 30 camera and coring stations on the bottom, both in the canyon and on its banks, were operated remotely from a surface

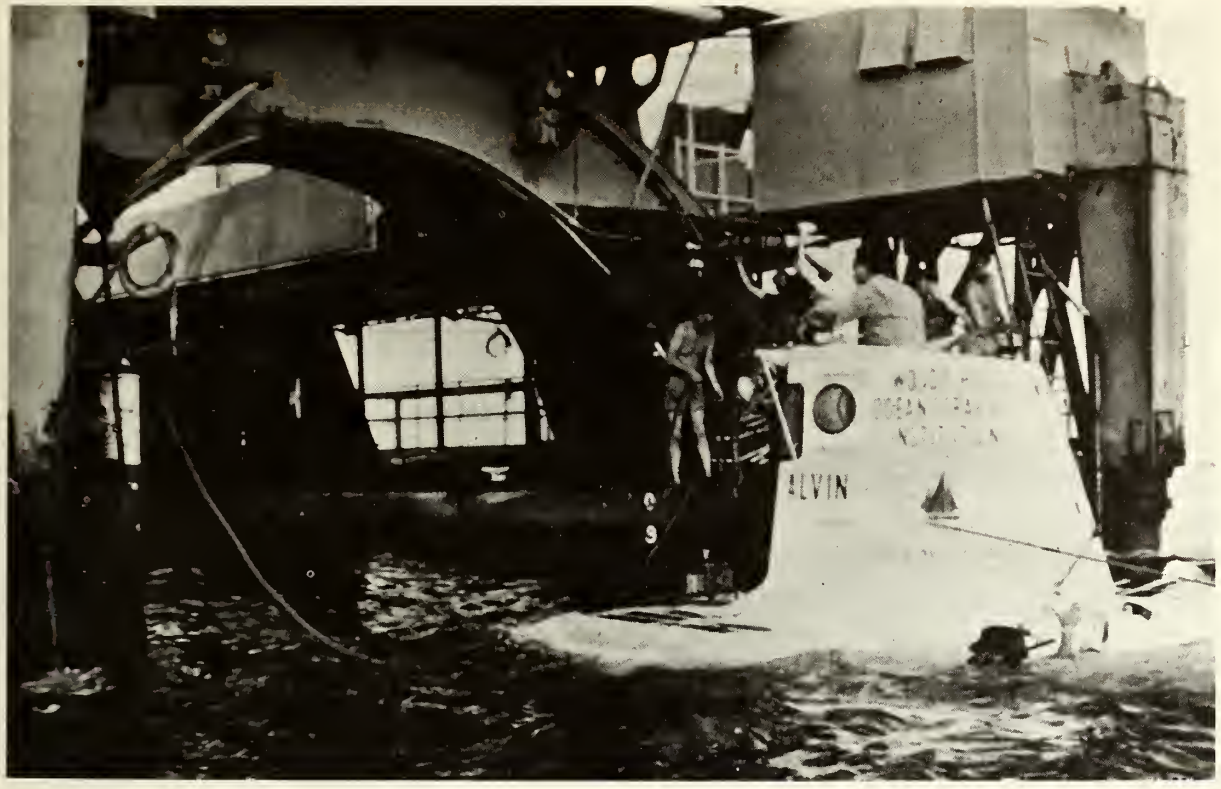


Figure 17.—Research submersible *ALVIN* entering support ship *LULU*.

vessel. To define the current activity, a current meter (General Oceanics, model 2010) was placed in the bottom of the canyon at a depth of 71 m during the dives in June and retrieved in September. In addition a series of reference stakes were planted from *ALVIN* in the vicinity of the meter to monitor possible sediment movement.

Although few bottom current measurements were made, it appears that flow reversal is common to submarine canyons. Unfortunately, the recording element in the bottom-mounted meter failed after 2½ days. Despite the limitations of such a short observation period, the data obtained serve to document the reversal of flow within the canyon. During this period upcanyon flow lasted longer but usually at much lower velocities than downcanyon transport, for which currents as high as 22 cm/sec were recorded. The limitations of these data make it difficult to assess the periodicity of flow reversals or any possible tidal relations. During the first 35 hours of observation, reversals appeared to occur about every 12–14 hours, closely approximating the tidal cycle recorded at Sandy Hook, N.J. During this time, downcanyon flow or minimum upcanyon activity appears to have coincided with periods of low tide at Sandy Hook. Such a relationship, however, was not found during the last 24 hours of recording. Just how the current reversal is related to tidal activity is not evident from our observations. Internal waves generated by tidal currents impinging on the continental margin probably influence the current reversals to some extent and thus further complicate the overall relationship. A progresssive vector diagram of the data from the bottom station reveals that during the 2½ days of operation the net transport was upcanyon (the canyon is oriented north-south at the current meter station). A bias in these measurements cannot be ruled out. In a relatively wide canyon like the Hudson, the tidal flow will be asymmetrically distributed at any one location between the zones of maximum flood and ebb, so that a single meter may show some bias.

There are, however, strong indications that over the long term there may be a net transport downcanyon. During the two series of dives, June 24–30 and September 7–14, approximately 66 bottom current measurements were made with a Savonius meter deployed from *ALVIN*. The actual measurements were for periods of 1–2 minutes, but the duration and direction of flow was monitored throughout the dive. By compiling these determinations of direction and duration for the measured velocities during all the diving days, an attempt was made to approximate the net transport. For the June

period 61 percent of the flow was downcanyon, whereas the September dives showed 83 percent of the transport downcanyon. These are necessarily crude estimates of the net transport, but it is believed that the short-period observations from the submersible do provide an important indication of current flow.

Based on the measurements from *ALVIN*, currents were relatively rapid (20–27 cm/sec) in the upper and central portion (150 to 1,000 m) of the canyon. Beyond 800 m, velocities were considerably less, commonly on the order of 2–5 cm/sec. These relatively few observations are far from adequate to document the bottom current conditions, but they do appear to present the generalized current regime along the axis of the canyon.

BAHAMA BANKS RESEARCH INVESTIGATIONS

NOAA supported twenty-seven missions at or near the habitat *HYDROLAB* 1 mile offshore at Freeport, Grand Bahama Island, Bahamas, at a depth of 50 ft. General objectives were continuous and comprehensive underwater on-site and area studies and assessments of the water chemistry, general ecology, and physical oceanographic parameters in the general vicinity of the *HYDROLAB*.

Mission 1

This mission was one of several under the general aegis of the University of Miami with J. Bunt, Chairman of the School of Marine and Atmospheric Sciences, as Principal Investigator. Other scientists working within this framework will also be designated as Principal Investigator for their particular mission. Thus, for mission 1 the Principal Investigator was A. Cobet, Naval Biomedical Research Laboratory, Oakland, Calif.

Date.—July 10–18, 1972.

Objective.—A microbiological study of habitat's internal environment, as it is affected by the presence and interaction of its inhabitants.

Procedures and results.—Samples from the air, bulkhead, and aquanaut's skin were plated to four media to determine the general and marine microbial populations *Staphylococcus aureus* and *Pseudomonas aeruginosa.*

Aerobiology

The number of airborne bacteria ranged from 25.1/ft^3 to 4.1/ft^3, averaging 14.8/ft^3. The bacterial population was diversified and not unusual in distribution. The number of airborne fungi was relatively constant with an average of 59/ft^3, consisting almost entirely of *Penicillium. Staphylococcus aureus* was not isolated from the air on day 3, but was during the remainder of the mission. *Pseudomonas aeruginosa* was not isolated from the air during the entire mission.

Human Microbiology

There are certain limitations on data obtained by swabbing an area on different occasions that lose the quantitative aspects of the results, but enable qualitative interpretations. This is because the manner of obtaining the sample and the area sampled may not be exactly the same from day to day.

The bacterial flora of the skin on all divers at the beginning of the program was essentially normal in both types of organisms observed and in distribution of colony types. By day 4, mid-dive samples showed changes in the bacterial flora. Aquanaut 1 was exhibiting *Staphylococcus aureus,* and aquanaut 4 had acquired two gram-negative organisms, *Citrobacter* and *Enterobacter* in their skin bacterial flora. At the end of the mission, day 7, aquanaut 1 retained *S. aureus;* aquanaut 2 had acquired *Klebsiella;* aquanaut 3 demonstrated gram-negative bacteria of the family *Enterobacteriaceae;* and aquanaut 4 retained the *Enterobacter.*

In summary, the divers acquired gram-negative flora during the mission; of particular interest is the *Klebsiella* by aquanaut 3. Aquanaut 1 retained a gram-positive flora, but had developed a large number of small pimples over his body which were due most probably to the *Staph* infection.

The nasal flora of the divers was essentially normal when the mission started. By midmission, day 4, aquanaut 4 had acquired a *Klebsiella* species as part of this bacterial flora; the other divers remained essentially normal. By the end of the mission all divers had acquired a *Klebsiella* species.

Ear samples were obtained only at the beginning and end of the mission. The bacterial flora was essentially normal at the beginning. There were no complaints of ear squeezes or infection during the mission, though two divers had acquired *Pseudomonas aeruginosa* infections prior to decompression. On the day after decompression, three of the divers complained of ear pain. Bacterial cultures showed that *P. aeruginosa* was the cause in aquanauts 3 and 4, and probably *Klebsiella* in aquanaut 2.

The habitat bulkheads were essentially normal in bacterial flora. The bulkhead of the entry well, however, was found to contain *Pseudomonas aeruginosa,* a probable source for the ear infections. Also *Klebsiella* was found on this bulkhead, a source that may have caused its presence in the skin, nose, and ears of the divers later in the mission.

The fungi in the habitat being almost entirely *Penicillium* does not represent a potential health

hazard to the divers, except to those with an allergy or hypersensitivity to the fungi. The level of fungi found in the air of the *HYDROLAB* was about 100 times the levels found in the *TEKTITE* programs, which were within normal limits. The only other consequence of the increased level of fungi is that deterioration of some of the equipment may be hastened. The source of the fungi may be food or other material dropping to the floor and falling through the deck grates.

Missions 2, 5, 9, 12, 16, 22, 27

These missions were conducted by various personnel of the Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of Miami, with J. Bunt as Principal Investigator. Other personnel and objectives and dates of missions are as follows:

Mission 2:

Objectives.—Systematic sampling to establish standing stocks; topographic transect survey.

Date.—July 11–16, 1972.

Habitat personnel.—J. Bunt (RSMAS), M. Wells, A. Ikehara, I. Strickland.

Surface support.—B. Soester, R. Trumbull.

Mission 5:

Objectives.—Sampling to establish standing stock distributions; marking and measuring "hard" and "soft" corals; testing techniques for metabolic measurements, i.e., photosynthesis and respiration; sampling of sediments through study area; further community structure studies.

Date.—Aug. 31–Sept. 5, 1972.

Habitat personnel—J. Bunt (RSMAS), C. Lee, I. Strickland, D. Wilson.

Surface support.—S. Pepper, B. Soester.

Mission 9:

Objectives.—Detailed survey photography of marked areas; measurements of marked corals; oxygen exchange in reef sediments; photosynthesis and respiration in "hard" and "soft" corals.

Date.—Nov. 15–21, 1972.

Habitat personnel.—J. Bunt (RSMAS), Z. Mount, I. Strickland, B. Soester.

Surface support.—T. Mount, Z. Sendry.

Mission 12:

Objectives.—Same as mission 9. Also detailed taxonomic survey for macroalgae and observations on fish behavior.

Date.—Jan. 3–8, 1973.

Habitat personnel.—Z. Mount (RSMAS), C. Lee, T. Mount, S. Earle.

Surface support.—J. Bunt, J. Vaught, L. Vaught, B. Soester.

Mission 16:

Objectives.—Same as mission 9. Also repeating measurements and observations to detect seasonal changes.

Date.—Feb. 4–9, 1973.

Habitat personnel.—J. Banbury (RSMAS student), M. Bonsignore, R. Smith, S. Cawthon.

Surface support.—Z. Mount (RSMAS), J. Wright.

Mission 22:

Objectives.—Same as mission 16.

Date.—Apr. 1–6, 1973.

Habitat personnel.—Z. Mount (RSMAS), D. Malloy, S. Exley, R. Frehsee.

Surface support.—J. Bunt.

Mission 27:

Objectives.—Same as mission 16.

Date.—June 3–8, 1973.

Habitat personnel.—J. Bunt (RSMAS), J. Banbury, R. Smith, R. Frehsee.

Surface support.—Z. Mount, P. Reinholm.

Procedures and results.—The results displayed here are highly condensed and only the general picture. Because the missions were often interdependent and generally related, the results are listed without referring to particular missions. In general, neighboring flora and fauna, reef ecologies, and topography were thoroughly determined, and the data are applicable to the Bahama-southeast Florida coastal reef and other regions.

During the first mission of the series approximately 25 line transects, each 10 m in length, were examined at depths between 15 and 30 m (fig. 18). The locations and sizes of hard and soft corals as well as sponges along each transect were recorded, and portions of each organism encountered were preserved for identification. Numbers of individuals and species, species sizes, and other parameters were determined (fig. 19). The data were scanned for recurrent species patterns.

For biomass determinations, samples were collected initially at 1-m intervals in rows 15 m long parallel to the axis of the reef, and at 25-m horizontal intervals from 15 m to 30 m deep. Material was placed in labelled plastic bags, sent to the surface, and frozen for later analysis on an automatic carbon analyzer. While sampling over the set grid, very few living corals were recovered. Most of the rock substrate is bare or colonized by macroalgae. Some extremely heavy stands of *Halimeda* were encountered.

Figure 18.—NOAA Corps aquanauts cementing a transect position marker to a coral head in the Bahamas.

Rates of oxygen production and consumption by hard and soft corals and sediments were determined. Visually insignificant algal populations of the sediments may be a major productive element of the reef system. Consumption and production data based on oxygen measurements over a grid of sites extending from 15 m to 30 m were obtained. Time course studies on the incorporation of radiocarbon into hard corals were undertaken.

Oxygen exchange in scleractinian corals and gorgonians was measured by fastening large transparent plastic bags around otherwise undisturbed specimens and measuring oxygen at the beginning and end of the experiment. Results suggest that the organisms are very close to compensation at these depths. Studies of oxygen production and consumption by sediments and corals, biomass distribution, and abundance and diversity of corals begun in previous missions were continued.

Samples to determine biomass distribution over a preselected grid pattern were collected. Oxygen exchange in sediments and production and consumption by hard and soft corals were determined. Transects were documented by photography.

Missions 3, 7, 10, 18, 24

Principal investigators.—E. Corcoran and R. Curry, University of Miami.

Dates.—Aug. 1–8, 1972 (mission 3); Oct. 1–7, 1972 (mission 7); Dec. 1–7, 1972 (mission 10); Mar. 1–7, 1973 (mission 18); May 1–7, 1973 (mission 24).

Objectives.—To determine the time-based distributions of and the possible relationships between the dissolved oxygen, pH, and the carbonate system.

Figure 19.—Unusual coral formation near *HYDROLAB* site.

Other parameters sampled were temperature, salinity, and carbon–14 production.

Procedures and results:

In May 1973 a program was opened to determine the time-based distributions and possible relationships among the dissolved oxygen, pH, and carbonate system. Throughout the entire program water samples were collected within a small parcel of water delineated by the physical boundaries of a surge channel 350 ft south of the *HYDROLAB* habitat. Nine sample positions were located in this water parcel in such a way as to form a vertical grid alined with the main axis of the surge channel. This grid consisted of three sample levels; the shallowest at 44 ft and the deepest at 63 ft. Three water samples were collected from each position every 4 hours for a period of 5 to 6 days. Besides water samples, the investigators collected samples for primary productivity estimates and recorded the water temperature at each of the nine sample positions.

On earlier missions (August and October) a number of mechanical and logistical problems hindered or prevented data acquisition. What data was collected was generally insufficient to make meaningful time-based observations. The data from these missions, however, are useful as collaboration for the findings of later missions.

Based on the findings of the *TEKTITE II* program, all dissolved oxygen samples were fixed in situ and analyzed in the habitat. The pH and total alkalinity samples that required no in situ treatment were processed in the habitat. Salinity samples were transferred to storage bottles and sent to the surface. Primary productivity samples were treated with

Figure 20.—*Left,* A portable underwater oxygen meter used in studies of coral reef productivity and oxygen depletion of the internal reef structure; *right,* diver using portable underwater oxygen meter to measure oxygen in the excurrent water of a sponge. Part of a study of the oxygen balance of coral reef communities.

a formalin solution and transferred to the surface for filtration and storage. We made exclusive use of the Curry water sampler, an in situ sampler developed for the *TEKTITE II* program and redesigned for this one.

Results demonstrate that in moderate to low sea states, the water column may be divided into two regions. The upper region extends from the surface down to about 50 ft. The lower region extends from about 50 ft to the true bottom, which in the area we studied was 70 ft. No part of the reef system extended into the upper region. This apparent zonation is probably due to the upper boundary of the reef system acting as a false bottom, essentially damping out or minimizing convective mixing processes.

The chemistry of the upper region appears to be influenced primarily by air-sea interactions. The lower region appears to be mainly controlled by the activity of the reef system biota and associated sediments. These regions rapidly blend together as the sea state increases beyond 5 to 6 ft, and they are not identifiable at sea states greater than 8 ft. The fluctuations in the chemical parameters measured showed greater extremes in the lower region than in the upper region or when no zonation was present.

The tides in the area are mixed semidiurnal and do not show any correlations with our data.

During periods of lower sea state there was good agreement between the dissolved oxygen, pH, and total alkalinity. During periods of high dissolved oxygen levels, the pH and total alkalinity decreased suddenly and considerably on occasion, probably

because of the spontaneous precipitation of calcium carbonate. Periods of slow recovery (up to 12 hr) always followed these sudden decreases.

Both in October and December, samples were collected every 15 minutes for a period of 3 to 4 hours to determine the rate of these sudden changes. No sudden changes were encountered during these periods of intensive sampling; however, the results strongly indicate that calcium carbonate precipitation is normally in short pulses. This would explain the continuous, high inorganic concentration in this area. Unfortunately, time and facilities did not permit additional sampling to prove or disprove spontaneous formation of authigenic calcium carbonate as the cause of the observed major fluctuations.

The dissolved oxygen followed expected seasonal trends, having lowest values during winter and highest mean values during the late spring and early summer. The dissolved oxygen rarely exceeded 110 percent saturation and never fell below 96 percent during the winter months. During summer the dissolved oxygen concentration was always at or above 100 percent, reaching as much as 140 percent saturation. This seasonal variation is the result of a number of factors: the length of day, water temperature, sea state, stability of the water column, etc. Most important is that the data show a net flux of oxygen to the atmosphere in this particular region.

An interesting, although initially shocking, phenomenon observed in the oxygen data frequently was two maxima and minima during a 24-hr period. One was during daylight hours; the other at night. Although the daylight maximum was around 2–3 p.m., the nighttime maximum was unaccounted for.

The nocturnal maximum is the result of photosynthetic activity in a highly productive area 4–5 miles to the east. This highly oxygenated water was transported to the study area by the prevailing long shore current.

The two-dimensional distributions generated from our data clearly show a very heterogeneous water column. This means that the organisms, spacially fixed in the water column, experience both high and low chemical extremes within relatively short periods of time. This could possibly explain the presence of only the more tolerant tropical fauna and flora, e.g., *Sargassum, Halimeda,* and *Dictyota.*

Missions 4, 8, 26

Principal investigator.—W. Schroeder, Texas A&M University.

Dates.—Sept. 11–18, 1972 (mission 4); Aug. 27–November, 1972 (mission 8); May 26–June 1, 1973 (mission 26).

Objectives.—A study of the role of zooplankton in the coral reef ecosystem, categorized as follows: Ascertain, on a seasonal basis, the composition and quantity of the open water zooplankton community as it arrives at the reef complex from the Northwest Providence Channel via local and regional currents.

Determine quantitatively the composition and distribution of planktonic and epibenthic organisms that have specifically adapted to the coral reef complex.

Utilizing the results from the above studies, more accurately describe the role zooplankton play in the energy cycle of the coral reef ecosystems.

Procedures:

Physical Oceanographic Data

Temperature.—Two vertical thermometer arrays were used to measure temperature. One array (shallow station 2) was located in 15 m of water approximately 20 m north by northeast of the habitat on a sand flat about 10 m from the shallow end of "Bunt's transect." This shallow array had thermometers at 15, 13, 11.1, and 9.4 m. The other array (deep station) was located in 26 m of water approximately 185 m south by southeast of the shallow array at the outer edge of the coral reef at the deep end of Bunt's transect. The deep array had thermometers at 26, 24.4, 22.9, 17.0, and 11.3 m. The in situ measurements taken with these two arrays were supplemented with surface temperatures.

A major addition to the project during mission 8 was a microscale thermal structure study of the waters immediately adjacent to *HYDROLAB,* utilizing expendable bathythermographs (XBT). Three transects were sampled on the two different days. Transect A was located approximately 2 miles east by northeast of the Bunt transect and ran from the reef dropoff out to sea for 1 mile. Transect B was located at Bunt's transect and ran from shallow station 2 to 2 miles off the reef dropoff. Transect C was located 2 miles west by southwest of Bunt's transect and ran from the reef dropoff out to sea 1 mile.

In addition, a modified transect B running from shallow station 2 out to 4 miles from the reef dropoff was sampled on two other days. These data provide a good first approximation of the fall thermal structure in and adjacent to the study area.

Salinity.—Numerous samples were taken both inshore and offshore.

Oxygen.—None; part of the titration apparatus was broken.

Currents.—Direction and speed recording current meters were located at shallow station 2 and deep station (see *Temperature* paragraph for station locations), whereas a direction-only meter was located at shallow station 1 (on top of a coral head in 13 m of water).

Deep station had two super-8 film recording meters; one at 23 m and the other directly above at 10 m. Shallow station 2 had two 16-mm film recording meters located in 12.2 m of water, but which malfunctioned.

Tides.—Tidal data were obtained by recording the absolute pressure which registered on the absolute pressure gage in the habitat.

Biological Data

Thirty-two zooplankton samples were taken with the diver-controlled underwater sampler, diver hand-held nets, or conventional surface plankton tows. Primary sampling areas of the saturation team were two 100-m transects; one north of the habitat on the sand flat and one south over the coral reef. Samples were taken at noon and midnight; 1 and 3 m off the bottom.

Results:

Preliminary review of the data collected indicated that all of the major objectives were met. However, it became evident during the missions that the hydrography of the area was far more complex and variable than had been expected. Hence, a more detailed sampling program must be designed and implemented during future missions.

Samples of water over and around the reef during mission 26 contained between 100 and 250 copepods per cubic meter of water. Dominant constituents of the copepod group included *Clausocalanus furcatus, Temora turbinata,* and many stage III, IV, and V copepodids of *Undinula vulgaris.*

These three species composed at least 70 percent of the copepods in the samples. Other less common species were *Oncaea venusta* and *Farranula gracilis.* Samples close to the bottom also had fewer copepods per cubic meter as compared with mission 8. As in mission 8, the dominant species included *A. spinata, C. furcatus,* and *T. turbinata.* Another cyclopoid, *Oithona plumifera,* was the dominant species at one reef station.

Chaetognaths were less abundant during the second mission, numbers ranging from less than one to 24 per m^3. *S. hispida* was still the most abundant species. The increase in numbers observed during an earlier mission likewise was found in those samples collected over the sand. During the day, less than one individual per m^3 was collected, whereas at night 23 per m^3 were taken—the maximum for all samples taken that night. During the day, 24 individuals per m^3 were caught in the "inshore" 10-m surface oblique tows. *S. helenae* and *S. enflata* were fairly common, as was *S. serratodentata. Krohnitta pacifica* and *Pterosagitta draco* also were present in small numbers. The last three species reached their greatest numbers at the "oceanic" surface oblique tow stations.

Night light stations.—Night lights around the reef and sand flat again attracted pontellids almost exclusively. The dominant copepod species were *Calanopia americana* and an unidentified species of *Labidocera. Labidocera wilsoni* also was present. *S. hispida* was the dominant chaetognath species in these collections. One unidentified species of *Spadella* was collected for the first time.

Mission 6

Principal investigator.—M. Heeb, University of North Carolina.

Date.—Sept. 11–15, 1972.

Objective.—To assess the chemical control of feeding behavior in marine invertebrates.

Procedures.—On numerous dives, both daytime and nighttime, many organisms were tested for their response to the oyster and clam extracts and to homogenates of coral and other animals. This was done by squirting small amounts of the solution or homogenate on or near the subject of interest and observing any response elicited. Of particular interest was any response that might be interpreted as an attraction response.

An experimental grid was laid out on the sea floor in front of the large picture window of *HYDROLAB.* The grid was made of 1/16-inch-diameter nylon string tied to steel pegs in such a way that the string was about 8–10 inches above the sandy sea floor. The overall grid size was 40 ft by 30 ft and sectioned off in both directions at 10-ft intervals. In the center of this grid was placed the open end of a length of plastic capillary tubing about 4 inches above the sea floor. The tubing was buried under the sand and run out of the grid. It was then taken up into the habitat to be connected to the infusion pump. The electrically operated (AC) infusion pump was then used to pump the various animal extracts through the tubing out to the center of the grid at constant rates which were varied from 0.1 ml/min to 4.0 ml/min.

Also tested were whole homogenates of the red scallop previously mentioned and the sea urchin *Diadema antillarum.* The extracts on hand varied in composition from whole homogenized tissue in phosphate buffer to various molecular weight range fractions.

In order to test the extracts for attractivity, the local starfish *Oreaster reteculatus* was collected by surface support divers. The starfish were placed randomly throughout the grid and photographed at regular intervals while the extract was pumped to the grid. Similar experiments were performed with sea urchins.

Results.—Animals that gave response to clam and oyster extracts are the red scallop (species unconfirmed), the sea urchin *Diadema antillarum,* and several crinoids. Of these animals only the urchin appeared to follow the scent. The starfish did not react favorably, and there were severe problems in handling the urchins. One was that the urchins fell prey to the fish population when placed in the grid on the open sandy sea floor. The starfish, it was learned, always moved off in the same direction regardless of conditions. The direction was toward the grass flats from which they came.

Mission 11

Principal investigator.—P. Cratin, Central Michigan University.

Date.—Dec. 12–19, 1972.

Objectives.—To study the concentration of oxygen in seawater as a function of time, depth, and temperature and the solubility of oxygen as a function of bubble size.

Oxygen Concentration in Seawater

Procedures:

Two distinct studies were carried out. The first of these dealt with the use of a Beckman oxygen meter in situ (i.e., in the habitat), and the other involved visual observations of water in a transparent sampler similar to that used at *TEKTITE II.*

Oxygen meter.—A large sample of seawater was collected in a plastic bucket and brought inside

the habitat. Air was sparged through the water until an equilibrium oxygen reading, 14.0 parts per million (ppm) at 27°C, was obtained on the Beckman meter. A biochemical oxygen demand (BOD) bottle was immersed in the bucket and filled with the seawater. The oxygen electrode fitted with a BOD collar was then inserted snugly into the top of the bottle, and the entire assembly taken to a sample site located about 25 ft outside the habitat port window. One diver manned the meter inside the habitat and gave signals to the other holding the BOD bottle and electrode. On signal, the diver would rise to a given depth and remain there until receiving another signal to ascend.

Transparent samplers.—Seawater was sparged with air inside the habitat until a concentration (as given by the meter) of 13.2 ppm was obtained. Samples were sealed in transparent bottles and taken to the surface from an initial depth of 50 ft. No bubble formation was observed at depths greater than 30 ft; however, above this bubbles appeared wherever nuclei were present inside the bottle. To document this, photographs were taken of a sample of seawater as it was brought up from 46 ft to 11 ft. The time involved in the ascent to 11 feet was 2–3 minutes.

Results.—The following tabulation summarizes the data obtained:

Beckman oxygen meter reading vs. depth

Depth (Ft)	*Meter reading* (Ppm)	*Time* (Min)
50	14.0	0
40	14.0	3
30	13.5	4
20	11.9	7
10	11.1	8

Obviously something highly unusual began at 30 ft —the abrupt drop in the reading from 14.0 ppm to 11.9 ppm, thought to be caused by the rapid degassing of the sample. Indeed, the diver had observed the beginning of bubble formation at 30 ft, and by the time he had reached 10 ft several large gas bubbles had formed.

Rapid though cautious removal of the rubber septum allowed some of the gas bubbles to escape from the bottle. Upon replacing the septum, the sample was "fixed" with Winkler reagents and analyzed shortly thereafter in the habitat. Again, a decrease in the oxygen level was noted—12 percent.

Solubility and Bubble Size

Preliminary work during the second trip to the *TEKTITE II* in 1970 indicated that bubbles from a diver's scuba exhaust did not cause any increase in oxygen concentration even at a depth of 50 ft. Since plankton can effectively saturate water during a "bloom," it was reasoned that the determining factor here was bubble size.

Initially, plans called for the passing of air through several glass fritted discs, each wih a fairly small (and known) pore size. Unfortunately, only the coarse filter (pore size 40-60 microns) could be used in this study; the pressures required to force air through the others was so great that it was decided not to risk an accident through explosion. Nevertheless, data obtained showed that bubble size and solubility are related.

Procedures.—The experimental part of this study was rather simple: samplers open at both ends were secured upright to a ring stand sitting on the base of the habitat. The rate of airflow into the samplers was adjusted to about 250 ml per minute, and the length of "treatment" was 1 minute.

Results.—In the first case studied, bubbles of approximately 1 cm in diameter were passed through the open bottles, but failed to increase the oxygen concentration to any measurable degree. When bubbles were broken down to submillimeter sizes, a 1-minute treatment resulted in an oxygen increase of 50 percent. This is really not surprising, since the solution process probably depends on surface area and the breaking down of one large bubble into, say, 1,000 small ones will result in a huge increase in surface area.

Mission 13

Principal investigator.—S. Earle, Los Angeles County Museum of Natural History.

Date.—Jan. 3–8, 1973.

Objective.—A study of adjacent flora and dependent fish.

Procedures and results.—In collaboration with the program of reef studies, reef vegetation was sampled and species of benthic plants recorded at 27 stations along three transect lines, each 200 m long, near the *HYDROLAB* site. Preliminary analysis of the plants yielded a list of 92 species, with depth distribution and substrate recorded for each. No extensive or luxuriant stands of plants were found. A short "turf" of mixed filamentous species was present on most rock surfaces and dead corals and was heavily grazed by herbivorous fishes, including 3 species of surgeonfishes, 10 species of parrotfishes, and 4 of damselfishes. Larger algae such as *Halimeda incrassata, Halimeda discoidea, Rhipocephalus phoenix,* and *Lobophora variegata* were common but nowhere abundant. The sparseness of the vegetation may be correlated with the abundance of herbivorous fishes.

Figure 21.—Collection of oil aging sample near *HYDROLAB*. The dark patch is a mixture of No. 2 fuel oil and sinking agent.

Observations were made on the habits of 29 species of plant-eating fishes in 12 families that were seen along the transect lines. Previous reports concerning the daytime activity and nighttime rest pattern for herbivorous fishes were confirmed.

Mission 14

Principal investigator.—A. Allen, Marconsult, Inc.

Date.—Jan. 16–22, 1973.

Objectives:

To develop tools and techniques for the in situ study of oily pollutants.

To conduct experiments on the physical behavior and biological effects of oil on the ocean floor.

To evaluate the applicability of the *HYDROLAB* habitat to this type of research.

Procedures and results.—Several mixtures of various oils and sinking agents were exposed to the subsea environment to determine sinking agent effectiveness, physicochemical aging, solubility, and vertical and horizontal migration (fig. 21). Whereas no significant loss of the sinking agents was detected, approximately 20 percent of the oil exposed in 30 samples was released over the 1-week period. During this time no measurable indication of physicochemical aging was detected. Additional, qualitative observations of vertical and horizontal migration of the oils showed no perceptible movement through or over the native sediments.

Biological observations were primarily directed toward development of techniques for use in later studies. Although some animal species reacted to the oil-sinking agent mixture, and very heavy doses inhibited the movement of bottom dwellers, coral polyps, etc., no gross toxic effects were observed throughout this phase of the work.

Operating from the habitat in the saturated mode proved to be a particularly effective procedure during experimental setup, observations, or recovery calling for extended on-scene work. Also, continuously working and living at the experimental site provided the flexibility to react to changing environmental or experimental conditions. Techniques and tools were developed that allowed the divers to perform the necessary tasks effectively without compromising safety or operational criteria associated with habitat operations.

Mission 15

Principal investigator.—W. Muellenhoff, EPA, Northwest Regional Laboratory.

Date.—Jan. 26–Feb. 1, 1973.

Objective.—To determine the degradation and exchange characteristics of treated sewage sludge in a benthic marine environment.

Results.—Measured dissolved oxygen uptake rates due to a layer of treated sewage sludge on the sea floor were found to be two to three times the average rates measured in bottom sediments of Long Island Sound and in marine sediments near Woods Hole, Mass. Also the oxygen depletion by the sludge significantly exceeded that measured in polluted river sediments downstream from municipal sewer outfalls on the Merrimack River. Under conditions of low horizontal and vertical mixing of bottom waters, such oxygen removal rates will deplete the bottom waters and significantly modify the biota of affected zones.

Total organic concentrations in the plume of the released sludge were found to be three times background levels recorded prior to the release. Preliminary analysis of near-bottom water samples indicates that organic carbon concentrations are very high. The total organic concentrations analyzer is being desensitized and recalibrated prior to further sample analyses.

Subsequent to the field research project, efforts were applied to the design and construction of a deep sea simulator to permit further evaluation of sludge breakdown at elevated pressures, low and high temperatures, and varying sea water flow rates. The research in the Bahamas will provide basic information required to formulate meaningful laboratory experiments.

Missions 17 and 20

Principal investigator.—J. Lord, University of Washington.

Associate investigators.—P. Kotzer, University of Washington; K. Stehling, NOAA, MUS&T office.

Dates.—Feb. 9–15, 1973 (mission 17); Mar. 21–23, 1973 (mission 20).

Objectives.—To record photographically and then measure stopping cosmic ray muon and star production rates, and to compare these rates to measurements underground.

Procedures and results.—The water mass between the *HYDROLAB* and the sky filters "stray" and unwanted cosmic and other radiation, thus permitting background-free nuclear emulsion stacks to be prepared in the habitat. Three hundred grams of emulsions were placed at 11 m depth, and 470 grams at 33 m depth. All the emulsions were encapsulated in pressure-tight steel cassettes. Later, another emulsion package was placed at 60 m.

About a month after emplacement, the 11-m and 33-m cassettes were retrieved and the emulsions developed within the *HYDROLAB*. They were then processed or separated and microscopically analyzed at the University of Washington Physics Laboratory. It was found that the stopping muon rates underwater agree with theoretical calculations. Such stopping rates are not readily verifiable in mines, i.e., underground, because of the heterogeneity of the rock or soil overburdens. Besides muons, several interesting star or collison processes of pi-mesons (pions) and neutrons were recorded. This very modest preliminary experiment demonstrated the usefulness and efficacy of the underwater technique. Deeper emplacement will result in more refined and new data.

Mission 19

Principal investigator.—C. Smith, American Museum of Natural History.

Dates.—Mar. 13–20, 1973.

Objectives.—To study the competition for space among cohabiting fishes; to investigate the interactions among species of cardinal fishes that occupy a small patch reef; and to determine nocturnal feeding activities.

Procedures and results.—A small isolated patch reef was selected within easy swimming distance and about 60 m northwest of the habitat. The reef was marked with a nylon line so that divers could find their way back and forth even if both lights failed during a night dive. The reef was mapped, measured, and photographed during the first few dives, and certain caves and other landmarks were named in order to facilitate taking notes on the resident fishes.

A total of 72 man-hours at the reef was spent on a thorough census of the resident and transient species and observing their behavior. Such census

data are the basis of all community analyses and are extremely difficult to obtain by any means other than direct, in situ observations. In this work there is no substitute for prolonged diving, and saturated diving from a habitat is the only way divers can remain at the site long enough to confirm their observations and to follow behavior patterns to their full extent.

Thirty-six species (288 individuals) were resident at the reef. Twenty-five other species visited the reef for brief periods, and six additional species shared the hunting grounds adjacent to the reef. Detailed records permitted analysis of the space and microhabitat requirements of nearly all of these except a few that were so secretive that they could not be observed efficiently. Spawning activity was observed in both of the two resident species of *Chromis,* but not at the same time. Present data do not explain why these species remain separate, but the answer may come in future experiments.

Cleaning gobies were present on the reef, and much information was obtained on cleaning station locations and on the species that utilized them. Such information promises important clues to the role of cleaners in community stability.

Especial attention was paid to the cardinal fishes. Four species were present around the reef, and comparative data were obtained on habitat preference, color patterns, and diurnal activity cycles.

Observations of locomotion patterns were made from the habitat. This is a promising technique which may be used more in the future.

Mission 21

Principal investigators.—K. Ackles and others, University of Western Ontario and the Defence and Civil Institute of Environmental Medicine, Canada.

Date.—Mar. 28–Apr. 22, 1973.

Objectives.—To study blood platelet phenomena involving saturated divers living in an underwater habitat.

Procedure.—Two groups of divers served as experimental subjects. Extensive hematological tests were performed on them in the *HYDROLAB* with a variety of apparatus and analytical devices. Hemoglobin concentration was tested, and platelet-poor plasma was obtained by centrifugation. Blood chemistry was tested for such substances as lipoproteins.

Results.—All but one of the subjects in both saturation dive groups demonstrated a fall in the circulating platelet count after surfacing. The extent of the fall was from 11.6 to 55.6 percent, with most subjects showing the lowest count 24–48 hr after surfacing. A variety of other changes in the hematology and blood chemistry were documented.

Mission 23

Principal investigator.—A. Roth, Loma Linda University.

Date.—Apr. 2–22, 1973.

Objectives.—There were two main purposes: To study the relationship of light intensity to pigment concentration in the coral *Acropora cervicornis,* and to determine the temperature tolerance of this species for short periods of exposure at elevated temperatures.

Procedures:

Light measurements.—In order to determine the light intensity, radient energy at various wavelengths was measured at surface level and about 50 ft down at the site of the *HYDROLAB* using a spectroradiometer outfitted for underwater measurements.

Pigment measurements.—Pigment content was estimated by measuring the absorbance of acetone extracts from the coral *Acropora cervicornis.* Various parts of the coral colony from levels 2, 17, and 20 m down were employed. Estimation of pigment content is complicated by difficulty in measuring the irregular surface area of coral samples. Two methods were employed and evaluated by correlation with pigment concentration.

Temperature tolerance measurements.—Temperature tolerance was tested by exposing the coral colonies to various, elevated temperatures in sea water for periods of 1 hour. The coral was then returned to its normal environment for 1 to several days and examined to see if still alive.

Results:

Light measurements.—As expected, virtually no red or infrared radiant energy reaches the site of the *HYDROLAB.* Integrated figures for the visible part of the spectrum (400–750 nm) show an 80-85 percent decrease in downward irradiance around the *HYDROLAB* compared with surface figures.

Pigment measurements.—Coral collected at the surface (2 m down) and on top of the coraline spurs (17 m down) showed no significant difference in pigment. The coral collected in partially shaded grooves (20 m down) showed a significant increase in pigment, probably involving a compensation for lack of ambient radiant energy.

Temperature tolerance.—Temperature tolerance tests on coral found near the surface showed that exposure for 1 hr at 36°C is lethal, but 34.5°C is not. Intermediate values were not conclusive. Coral collected 17 m down appeared to be partially destroyed by temperatures of 34°C and 34.5°C for 1 hour. A temperature of 35°C was lethal for one

test and not for another. The data suggest that surface coral is less sensitive to higher temperatures than is coral 17 m down.

Mission 25

Principal investigator.—T. Bright, Texas A&M University.

Associate investigators.—T. Burke, C. Tresslar, Texas A&M University.

Date.—May 16–21, 1973.

Facilities.—Habitat *HYDROLAB;* General Electric closed circuit underwater breathing apparatus.

Objectives:

To establish and more thoroughly document the relationship of morning and evening acoustical changeover to morning and evening behavioral changeover in three species of Holocentridae (squirrelfishes).

To establish and document the relationship of acoustical and behavioral changeovers to diel fluctuations in light intensity and to the times of local sunrise, sunset, and twilights.

To further relate a variety of sounds identified during July 1971 to aggressive and defensive behavior in the squirrelfishes.

To further document several varieties of vagrant evening fish sounds detected in June 1970 and to relate them to observed nighttime patterns of locomotion and feeding.

To investigate the effects of dissolved methane on the behavior of the cave-dwelling reef fishes *Holocentrus rufus* and *Myripristis jacobus* and a territorial damselfish *Eupomacentrus dorsopunicans.*

Results:

The study site was a cave approximately 600 ft away from *HYDROLAB* in which populations of the two species occupied territories during the daytime. Previous observations had indicated interspecific and intraspecific acoustical exchanges between the fishes in the cave. Investigations into the nature of these exchanges were continued by recording over 5 full days and observing behavior through the use of scuba and the General Electric Rebreather diving unit. Significant differences in the behavior of the fishes were detected by divers when using Rebreathers, which are noiseless and bubbleless, as compared with scuba, and two Rebreathers were used wherever possible.

The most intense observations were made during evening and morning twilights when the fishes leave and return to the cave. These times were marked by crepuscular peaks in acoustical activity. Upon leaving the cave at night to feed, *Holocentrus rufus* proceeded generally to the face of the reef and the adjacent sand flat. Choruses of vagrant evening staccato calls were detected on the sand flat for a few hours after evening twilight and were attributed to *H. rufus. Myripristis jacobus,* upon leaving the cave, hung in the water above; no sound from this species was detected at night.

Preliminary experiments attempted to gain an impression of the effects of dissolved methane on the behavior of the above cave-dwelling species and on *Eupomacentrus dorsopunicans,* a territorial damselfish. Bottled methane was bubbled into the water through a diffuser in the vicinity of the fishes' territories, and their behavior observed concurrently. Compressed air was used as a control. No conclusions were drawn, but two hypotheses were advanced: The overt behavior of territorial reef fishes in their natural habitat is not significantly altered by low concentrations of dissolved methane in the water; dissolved methane attracts large predaceous fishes such as groupers and barracudas.

PUERTO RICO INTERNATIONAL UNDERSEA LABORATORY (PRINUL) RESEARCH PROJECTS

The MUS&T office funded and participated in various scientific missions in and from an underwater habitat[6] located near Mayaguez, Puerto Rico. The habitat, capable of supporting five divers, normally operates at about 50–100 ft deep and can be maintained at ambient or sea level pressure.

The marine environment of the west coast of Puerto Rico is characterized by the abundance of alluvial sediments originating from the many rivers emptying on this coast. The sediment places constrictions on reef formation which will prove interesting as the effects of siltation come to light in this program. This natural stress on the environment can be a situation for study that has probably been uniform over a long period of time.

The missions described here were within the context of Puerto Rico's broader coastal marine resource and evaluation programs.

Mission 1

Principal investigators.—J. Wells, MUS&T/NOAA; D. Olsen (PRINUL).

Associate investigators.—M. Sheen, PRINUL; J. Larson, Collonades Undersea Research Center, Riviera Beach, Fla.

[6] The habitat itself (fig. 2) is named LA CHALUPA but is also identified by the organizational acronym PRINUL. It is owned and operated by the Puerto Rico Marine Resource Development Foundation.

Date.—Nov. 18–Dec. 1, 1972.

Objectives:

Map a large area adjacent to the study site.

Measure the oxygen metabolism of mixed benthic communities and selected individual species.

Describe the community types that exist within the study area with respect to species composition and diversity.

Describe the currents within the limitations set by the equipment available.

Observe feeding and reproductive behavior.

Procedures and results:

Mapping

Four 0.25-inch transect lines (200 yd long) were laid. At each 10-m interval the aquanauts attached a light line which was marked in 5-yd increments. They then swam the line out on a compass course (either north or south depending on the quadrant) until they reached the 100-yd mark on the line. The line was rewound on a reel back to the origin, and the depths (measured with a gage which had been calibrated in a decompression chamber) were recorded.

At each point measured, the community was classed as belonging to one of six types so that an overlay showing the distribution of these biotic assemblages can be constructed.

At the east 40-yd mark, the technique was changed to permit greater detail in mapping the reef area itself. At this point the long line was anchored to the bottom, and another short line, marked in 2-yd increments, was attached. This line was then swum due east until it reached the edge of the reef. At the edge of the reef it was staked to the bottom, and one aquanaut swam the line up to the 30-ft upper excursion limit. The line was held so that it formed a constant angle with the bottom, which was estimated with a diver's compass with an error of possibly less than 5 degrees. The first aquanaut then swam along the line and recorded the depth at 2-yd increments. The quadrat area was constructed along the east line from a reference point to the upper excursion limit and of 1.25-in. line laid out in 5-yd squares paired at each level. The quadrats include all of the observed community types from algal plain to some of the shallow water *Acropora* and *Porites* assemblages. The very shallow gorgonian community is not represented within the quadrats and will be investigated during aquanaut training. The quadrats were paired so that one at each level served as an experimental area and the other was left undisturbed as a control. The data were plotted initially as taken on a teletype so that initial contour lines could be drawn and the aquanauts could view the results and concentrate their efforts accordingly. The data from the reef itself were corrected for angular deviation with standard trigonometric adjustments so that the final map could have the contours placed in a true horizontal coordinate system.

A total of 248,000 ft^2 were mapped in addition to the detailed quadrat map. The quadrat area was mapped in the same manner except that measurements were taken every yard to permit greater detail within the study area. Additional photographic information was gathered that will permit a three-dimensional representation to be constructed.

Community Respirometry

The ratio of productivity to respiration has been suggested as an indicator of community stability. Similar significance has been assigned to species diversity. The respirometry studies concentrated on describing both the ratio and species diversity from four communities (Algal Plain, Halophila, Sand, Gorgonian) and several individual species of hard corals and gorgonians.

Determinations of benthic metabolism (photosynthesis and respiration) were made by measuring the rate changes in oxygen pressure inside of clear plexiglass domes sealed over a portion of the bottom. The partial pressure of oxygen (pO_2) was recorded on a small strip chart recorder housed in plexiglass or read from the meter of an "instamatic" oxygen/light meter. Small pumps circulated the water past the tip of an oxygen electrode and back into the domes. Together with the light data, obtained with a recording photovoltic system, it is possible to calculate the light dependence curves of oxygen evolution or consumption, the compensation light intensity and time of day, the rate of photosynthesis and respiration, and net benthic productivity.

Light records were also gathered by means of a submersible photometer and a recorder in the laboratory. A thermistor was placed at the photometer site, and temperature was recorded along with the current.

Species Composition and Diversity

Species diversity calculated from five samples collected from beneath the domes used in the respirometry studies ranged from 1.1424 to 0.7855 nits as calculated from the standard Shannon-Weaver formula. These data suggest that the Halophila community may be an early successional state on the edge of the sand area surrounding the reef, where diversities of 0 and 0.2743 were recorded for two samples.

Currents

Current speed and direction were recorded from an ENDECO Type 110 remote reading current meter. Since observations were recorded incidentally to the primary tasks, there are many gaps in the data; however, several phenomena emerge. During the first 5 days of the mission (Nov. 18–23) there were currents from two different directions (NW and SE) which reached a maximum of 0.9 knots on Nov. 21. The bidirectional nature of the currents was quite clear. From Nov. 21 to Nov. 23 there was a strong surge originating from a tropical depression that made current measurements meaningless. During this time, however, the current meter measured surges up to 1.3 knots. From the day the surge died down (Nov. 25) until the end of the mission the current was negligible, rarely exceeding 0.3 knots.

Behavioral Observations

Sparisome radians: Observed feeding on *Porifera porites.*

Calamus pennatula: Feeding among bottom sediments, food unknown.

Eucinostomus sp.: Feeding among bottom sediments, food unknown.

Caranx ruber: Feeding among bottom sediments, food unknown. Most active from early morning to afternoon. One larger individual was observed feeding with *Mulliodicthys martinicus,* apparently stealing food from it. The *C. ruber* chased away other conspecifics.

Mulliodicthys martinicus: Feeding on *Porifera porites* and on unknown food among bottom sediments.

Dactylopterus volitans: Feeding on *Porifera porites* and on unknown food among bottom sediments.

Acanthurus sp.: Observed feeding on filamentous algae on the *LA CHALUPA.*

Clupeidae: Juveniles were observed at night feeding on small plankton.

Gramma loreta: Appears to be a particulate plankton feeder.

An octopus was observed in one half of a large pelycypos shell with mature eggs that were in the act of hatching. The individual larvae were approximately 8 mm in length. The adult was approximately 12 cm across the arms. Several of the red algae were observed with cystocarpic structures apparent on the thalli. Cleaning behavior was observed for *Goblosoma evelynae* and *Perriclimines petersoni,* which were observed cleaning the grouper *Epinephilus guttatus.*

Mission 2

Principal investigator.—A. Dahl, Smithsonian Institution.

Date.—Dec. 18–31, 1972.

Objective.—An analysis of the distribution and community structure of benthic algae as related to reef food webs.

Procedures.—Detailed collections were made from precisely recorded locations throughout the study area, together with estimates of density and relative abundance in 0.25m^2 quadrats. On the reef, quadrat data included areas of algal-covered substrata sketched in the field and later checked against photographs, with the area determined by planimetry. On the plain, individual plants and clumps were plotted with generic identifications. Five 0.25 m^2 quadrats were mapped at 20 m from the reef, and another five at 40 m. Two line transects perpendicular to the reef were also used to record the transition from reef to algal plain, using presence or absence data for each square meter along the transect line. Area coverage of the benthic associations on the plain was determined by planimetry from photographs taken at 3 m above the bottom. A complete set of voucher specimens has been deposited in the U.S. National Herbarium.

Observations on the reef.—On the deeper reef accessible from the laboratory (10–18-m depth), the effects of sedimentation were apparent in the sparse macroalgal cover. Only a small fraction of the 20–60 percent of the surface not occupied by animals had visible algae. Most plants were on vertical surfaces—projections or edges where less sediment could accumulate. The largest alga observed on the reef was *Valonia ventricosa,* reaching 30 mm in height but generally coated with sediment and thus almost invisible. No other plant reached over 10 mm in height. Individual plants were thinly distributed even in favorable locations, and some, such as *Sphacelaria,* were almost completely immersed in the layer of sediment. Crustose coralline algae were present but not abundant. Boring algae were common in the rock substratum, and dissolving the rock in acid left a tangled mass of filaments retaining the form of the original rock. Although heavy sedimentation occasionally kills patches of living coral, making space available, algal colonization seems equally discouraged.

Other factors besides the sediment and turbidity may contribute to the limited macroalgal development. Grazing pressure, particularly by fishes during the day and urchins at night, appears to be very high. Clumps of *Udotea conglutinata* and *Solieria tenera* transplanted to various locations on the reef

were devoured within 24 hr, leaving only the *Udotea* holdfasts and inaccessible bits in the attachment clips. When *Solieria* branches were placed in cages of 6-mm galvanized wire mesh, either entirely closed or open toward or away from the reef, all plants accessible to fish vanished, whereas those exposed toward the reef or fully enclosed were untouched. Polypropylene survey lines present for a month at the site were covered with a heavy algal and bryozoan turf on the plain, but quite clean where they crossed the reef.

Also the reef morphology is not particularly suitable to dense algal development. Solid corals and platelike *Agaricia* species predominate, with the latter often loose in reef depressions, leaving few interstices to provide protection from grazing while still receiving enough light.

Observations on the algal plain.—In contrast to the sparse algal development on the reef, the sandy plain stretching out from its base seemed the underwater equivalent of a prairie scattered with wildflowers. The ecology of this habitat seemed particularly interesting, and the opportunity to live in the environment for 2 weeks under a variety of conditions permitted observations that might have eluded the surface diver.

The substratum consisted of a coarse sand, with *Halimeda* segments as an obvious component and occasional chunks, forming a layer about 50 mm deep over a fine, dense, almost claylike deposit. The percentage of fine sediment increased toward the reef, with the bottom approaching a soft ooze at the reef base. Several days of strong, reversing currents swept the area during periods of tidal extremes, though slack periods permitted some of the fine suspended material to settle out. Wave surges also created considerable water motion at the bottom.

In these rather unfavorable conditions for benthic macroalgae, a distinctive plant-animal association had developed capable of stabilizing large areas of the bottom. The association is composed of a number of deeply rooted algae such as *Halimeda*, *Udotea*, and *Caulerpa* imbedded in a variety of epiphytic sponges that have partially engulfed the algae and spread out over the bottom, forming sizable clumps. Other algae are also enmeshed in the clumps, such as *Anadyomene*, *Solieria*, and several *Gracilaria* species, and smaller filamentous forms cover most available points of attachment. The algal thalli seem unaffected by the covering animal layers which can reach 10 mm or more in thickness. Tunicates and other benthic animals also are present in large numbers. The result is extensive hummocks of animal and plant material interspersed with clear current-swept sandy areas not unlike some terrestrial desert and sand dune-plant communities. Some large (2 m), shallow (30 cm) depressions left by the laboratory during mission 1 had accumulated large quantities of algal sponge clumps in the ensuing month, suggesting that strong current may dislodge or shift some of the clumps, which may then reestablish themselves during calm periods. Large red algae (*Laurencia, Gracilaria, Halymania, Dasya, Chendria*, etc.) are also common, almost invariably attached to a shell or lump of coral rubble just below the surface of the sand.

The biomass (wet weight) of one randomly selected 0.25 m^2 quadrat 40 m from the reef on the algal plain was determined in collaboration with the Puerto Rico Nuclear Center. The complete contents of the quadrat were carefully sorted and weighed in the laboratory, and the results appear in the following tabulation:

Wet weights of major constituents in an 0.25 m^2 quadrat, algal plain

	Wet weight (G)
Halimeda sp.	37.8
Udotea sp.	11.6
Anadyomene stellata	8.5
Laurencia sp.	4.5
Gracilaria sp.	2.3
Caulerpa mexicana	2.0
Solieria tenera	1.6
Dictyota sp.	0.5
Valonia ventricosa	0.5
Caulerpa microphysa	0.4
Dictyurus occidentalis	0.3
Total algae	70.0
Sponges	988.0
Tunicates	8.8
Bryozoans	2.3
Mollusks and worms	2.2
Gorgonians	2.2
Total animals[1]	1,003.5

[1] Does not include rapidly mobile crabs and brittle stars of which small numbers were present.

Although *Halimeda* was not usually conspicuous, it proved to have the largest wet weight of any alga. The high value for *Anadyomene* represents a single large clump that happened to be included; no generalization concerning species proportions can be made from the small sample. The sponge category included some miscellaneous animal material and debris and was not sorted further.

Some preliminary feeding experiments were conducted with transplanted alga and a small cage array.

Samples of *Udotea* and *Solieria* clipped to blocks 1 and 2 vanished within 24 hr except for the *Udotea* holdfast, whereas a control at the habitat remained intact. The cage array included a closed cage of 6-mm hardware cloth, a similar cage covered with mosquito nettings, a cage open at the top, a cage open at the bottom, a clip suspended at the same height as the clips in the cages, and one at the substrate level. *Halimeda* plants put in the array at 25 m on the algal plain were undisturbed after several days, but *Solieria* plants in the array placed on the reef just south of quadrat 3 were cropped to the clip in the two open clips and in the cage open from the top, whereas those in the closed cages and the cage open from the bottom were undamaged. Algal plain species are apparently rapidly devoured on the reef, presumably largely by fishes. The poor visibility made more direct feeding observations difficult.

Mission 3

Principal investigator.—B. Harger, University of California, Santa Barbara.

Date.—January 1973

Objectives.—To study the operation of an underwater microscope in the natural environment, and to analyze, via microscopic and macroscopic sampling, the growth and disposition of soft bottom benthic forms with particular emphasis on the algae.

Procedures.—Settling plates were placed on the reef and up to 15 m away from it. Rain gages were placed between the reef and soft bottom, (3) at 5 m from the reef on the soft bottom, and (4) at 15 m from the reef on the soft bottom.

Sedimentation effect on the light penetration was shown by measuring light transmittance through 0.20×0.20-m translucent fiberglass settling plates placed on the bottom near rain gages 2, 3, and 4. Light was measured using a Weston selenium photovoltaic cell mounted with a cosine collector.

Soft bottom benthic forms were macroscopically sampled at eight random points along a 50-m transect line perpendicular from the reef. At each random point two contiguous 0.50×0.50-m square quadrats were mapped and photographed. Brillouin diversity and evenness were computed,[7] as well as frequency (percent of samples in which an entity is present) and density (of those samples, average number of individuals per sample) for the entities noted. Lack of scientific refinement in invertebrate identification was due to the investigator's inexperience with the local organism. Recurrent group analysis was carried out using Fager's [8] method.

At the beginning, middle, and end of the transect line the bottom was microscopically examined to determine microscopic properties correlative with macroscopic biotic changes observable along the transect gradient. Sediment samples were gathered at the microscope stations.

Results.—The following tabulation summarizes rain gage readings in ml of sediment.

	Rain gage—			
	1	2	3	4
	(M1)	(M1)	(M1)	(M1)
Initial, Jan. 22	1	4	1	Gone
After brushing	5	11	10	Do.
Initial, Jan. 28	4	8	11	Do.
After brushing	8	17	14	Do.

After 6 days, sediment on the settling plates near rain gages 2, 3, and 4 reduced illumination to 0%, 20%, 27%, and 48% (uneven sediment distribution on the surface) of the light transmitted by a clean plate.

Tables 10 and 11 summarize data collected in macroscopic surveys. Recurrent group analysis revealed seven recurrent groups. In order of decreasing importance these were:

Group 1: Species 1, 3, 4, 8, 10, 15, 26, 30, 34, 35
Group 2: Species 20, 36
Group 3: Species 21, 37
Group 4: Species 39, 40
Group 5: Species 9, 33
Group 6: Species 2, 6
Group 7: Species 12, 32

Groups 1, 4, and 5 had affinities between members. The microscopic survey data supported subjective appraisals of the sediments.

[7] Pielou, E. C., 1966, The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology* 13: 131–144.

[8] Fager, E. W., 1957, Determination and analysis of recurrent groups. *Ecology* 38: 586–595.

Table 10.—*Diversity and evenness for plants and animals*

	Distance from reef	Species per $m^2/4$	Individuals per $m^2/4$	Diversity	Evenness
	M	*No.*	*No.*	*Bits*	
Plants ...	2.5	0	0	0	0
	2.5	1	1	0	0
	5.0	7	32	1.9	0.56
	5.0	0	0	0	0
	9.5	2	6	0.7	0.10
	9.5	0	0	0	0
	16.5	5	24	1.7	0.55
	16.5	10	30	2.2	0.5
	34.0	10	39	2.4	0.64
	34.0	8	42	2.4	0.63
	39.5	9	39	2.5	0.67
	39.5	10	33	2.2	0.63
	43.0	7	45	1.6	0.43
	43.0	9	77	2.1	0.46
	45.0	10	84	2.0	0.45
	45.0	11	76	2.1	0.47
Animals ..	2.5	0	0	0	0
	2.5	0	0	0	0
	5.0	2	2	0.5	0.13
	5.0	0	0	0	0
	9.5	0	0	0	0
	9.5	0	0	0	0
	16.5	4	62	0.6	0.15
	16.5	2	2	0.5	0.13
	34.0	8	86	1.8	0.39
	34.0	6	45	1.6	0.44
	39.5	5	45	1.6	0.23
	39.5	9	113	2.4	0.48
	43.0	4	15	0.9	0.36
	43.0	6	53	2.1	0.53
	45.0	7	100	2.2	0.46
	45.0	5	72	1.5	0.37
Plants and animals ..	2.5	0	0	0	0
	2.5	1	1	0	0
	5.0	9	34	2.1	0.59
	5.0	0	0	0	0
	9.5	2	6	0.7	0.10
	9.5	0	0	0	0
	16.5	9	86	1.7	0.37
	16.5	12	32	2.4	0.69
	34.0	18	134	3.0	0.56
	34.0	14	87	2.9	0.62
	39.5	14	84	3.0	0.52
	39.5	19	146	3.1	0.57
	43.0	11	60	2.2	0.53
	43.0	15	130	3.0	0.58
	45.0	17	184	3.1	0.54
	45.0	16	148	2.8	0.52

Discussion.—The interrelated physical factors of current, sedimentation rate, and partical size distribution are influencing the soft bottom as well as the organisms living there. Underwater microscope observations and collected sediment samples revealed a loose fine-grain sediment accumulation near the reef, a belt of very little fine-grain sediment from 5 to 15 m from the reef, and, farther from the reef, a matrix consisting mainly of coarse-grain sediment with interstitial fine-grain sediment bound by mucilaginous substances.

The macroscopic survey revealed a special composition not significantly different from that of mission 20. Number of species and individuals, diversity, and evenness show a gradient of increase to the 34 m sample. Diversity and species richness were relatively high compared with samples taken by Harger in Hawaii. The high degree of evenness with densities nearing 800 individuals per m^2 indicates a well-packed community. Recurrent group 1 includes all major organisms and indicates that the community is limited near the reef as a whole rather than on an individual species basis.

Table 11.—*Key for species' names, numbers, frequencies, and densities*

	Species number	Frequency	Density
		Percent	*Individuals per m²/4*
Algal species name:			
Schizothrix sp.	1	69.2	17.8
Halophila baillonis Ascherson	2	7.7	5.0
Udotea conglutinata (Ellis and Solander) Lamoreux	3	92.3	4.4
Halimeda discoidea Decaisne	4	92.3	11.4
Unidentified foliose red alga	6	7.7	1.0
Chrysymenia sp.	7	23.1	1.3
Unidentified filamentous red alga	8	76.9	6.3
Gracilaria sp.	9	46.2	1.7
Laurencia sp.	10	69.2	2.7
Hypnea like red	12	7.7	1.0
Botryocladia pyrifornia (Borgen) Kylin	13	7.7	2.0
Unidentified blue-green alga	14	15.4	1.0
Acanthophora spicifera (Vahl) Borgesen	15	46.2	1.5
Anadyomene stellata (Wulfen) C. Agardh	16	30.8	1.3
Valonia macrophysa Kutzing	17	7.7	1.0
Caulerpa microphysa (Weber-Van Bosse) J. Feldmann	20	15.4	1.5
Caulerpa racemosa (Forsskal) J. Agardh	21	15.4	6.5
Caulerpa ashmeadii Harvey	22	7.7	3.0
Dictyota species A	25	53.8	1.7
Dictyota species B	26	69.2	2.2
Invertebrate entity name:			
Red sponge	30	100.0	5.9
Clear sponge	31	45.5	21.8
Black sponge	32	9.1	4.0
Solitary tunicate	33	45.5	30.6
Grey spotted colonial tunicate	34	81.8	15.3
White colonial tunicate	35	81.8	9.1
Orange and red colonial tunicate	36	18.2	2.0
Hydroid large branched	37	18.2	1.5
Hydroid small	38	18.2	3.0
Pseudopterogongia ahericana	39	54.5	3.3
Burrowing anemone	40	54.5	1.8

Physical limitation of the community seems the most likely prospect. Evidence indicates that the community coagulates and stabilizes the substratum. Near the reef the substratum is subjected to higher sorting forces from wave surge and is unstable, showing surge-formed sand waves. *Schizothrix, Halophila,* and *Udotea* are able to survive sand depth changes and are stabilizers in high stress areas near the reef.

Mission 4a

Principal investigator.—G. Barlow, University of California.

Date.—February 1973.

Objectives.—The chief objective of this project was to gather data on selected aspects of the ecology and behavior of those fish species that seemed to offer the best opportunity for the study of social behavior in relation to feeding and use of space. Because of their relative abundance, ease of observation, and importance in the food web of the coral reef, parrotfishes received the most attention. The hamlets, members of a very different feeding guild, were observed when conditions were unfavorable for gathering data on parrotfishes.

Results.—Four species were studied in detail: the stoplight parrotfish *(Sparisoma viride),* the redband parrotfish *(S. aurofrenatum),* the princess parrotfish *(S. taeniopterus),* and the striped parrotfish *(Scarus croicensis).* The stoplight is more constrained to a hard reef than the other species, and only midphase fish were regularly encountered below the upper

excursion depth of 30 ft. Their numbers showed little day-to-day fluctuations. These fish were well spaced and usually solitary when feeding. However, a single large midphase fish with a smaller individual was sometimes seen. Other transient groupings included a surgeon fish or another parrotfish, such as the redband. The vagility index (2.3 m^2) was low, indicating restricted movement.

The redband occurred in all situations in the northwest sector, except over open sand. It was usually solitary. The midphase fish were sometimes joined briefly by one or two smaller conspecifics or another species of parrotfish. The terminal phase was nearly always solitary, but was sometimes near a midphase conspecific. The terminal phase swam more up off the bottom than the midphase; it was also more widely spaced and moved about more (vagility about 5 times as much). The midphase fish were present in comparable numbers on successive days.

The princess were to be found everywhere on the reef. Terminal phase fish were common only the first few days of the mission and seemed to behave much as terminal phase striped parrotfish. The midphase princess moved alone or in groups of 2–4 fish. They seemed highly mobile; some days being common, other days rare. Their vagility index (5.9 m^2), however, was relatively low, probably because when present they fed steadily and were not involved in reproductive chasing.

The striped parrotfish was the most variable in its occurrence. On some days no midphase fish were seen, and only a few terminal fish were apparent. Sometimes both were present in the morning but absent in the afternoon. More often, it seemed, they started appearing near noon and became abundant in the afternon. The midphase fish tended to be solitary and less vagile when rare. As their numbers increased, they were inclined to form groups and to move considerable distance. Terminal phase fish were the opposite; when few were around they wandered about. But if many were present, they stayed within a much smaller area, being hemmed in by adjacent terminal phase fish.

Mission 4b

Principal investigator.—G. Losey, University of Hawaii.

Date.—February 1973.

Objectives.—Objectives were to initially survey the behavioral mechanisms of cleaning symbiosis in some Caribbean reef fishes. Cleaning involves the removal of ectoparasites and obviously has evolved independently in the Atlantic, Pacific, and even fresh water areas. A comparison of the behavioral and ecological mechanisms evolved in these separate areas would reveal much about the evolution and maintenance of this symbiosis. The Caribbean is of particular interest because of doubt as to the necessity of ectoparasite removal for the health of reef fishes. An early qualitative study suggested that cleaning was vital, whereas more recent quantified studies in Hawaii suggest that it may be of lesser importance. Because the behavior of Caribbean cleaners is poorly known, preliminary studies such as this were needed.

Distribution of Cleaner Fishes

Procedures.—The NW and NE quadrants of the study area were chosen because of their greater abundance of reef fishes. The abundance of *Gobiosoma evelynae* was estimated by laying a transect line over the reef from the N–S transect line and west until out of the range of abundant coral heads. The experimenter swam each transect line and noted the location of each coral head under the transect line of greater than 1 ft diameter, the diameter of the coral head, and the presence or absence of cleaners.

Results.—There was much cleaning on top of the reef, above the shallow excursion limit which was not observed. Within the excursion range, *Gobiosoma evelynae* (and *G. genie*) and juvenile *Thalassoma bifasciatum* (yellow phase) were by far the predominant cleaner fishes. (Various cleaning shrimps were seen but not studied.) Cleaning stations were found on 19 percent of the coral heads. The mean size of the coral heads sampled was estimated as 1.6 ft. If the transect area likely to be sampled is taken as the mean diameter of the coral head multiplied by the length of the transect, the data indicate about one coral head or potential cleaning station per square yard. The diameter of the coral heads that actually were cleaning stations ranged from 1 to 4 ft with a mean of 2.3 ft. Thus cleaning stations were found on slightly larger-than-average coral heads, with a density of about one in every 10 square yards. A total of 11 *G. evelynae* were found on the stations.

Eleven juvenile *Thalassoma bifasciatum* were found on the entire reef west of north transect yardages 130 to 200, an estimated coral reef area of about 2,000 square yards. This yields an estimate of about one per 100 square yards, but they were aggregated on only four cleaning stations, giving a cleaning station estimate of one per 500 square yards. A much greater density may well occur on top of the reef.

In all cases where *Thalassoma bifasciatum* were found, its cleaning stations were shared with two

or more *Gobiosoma evelynae*. Small buoys placed on the stations showed that their locations were stable for at least 1–2 weeks in all cases but one. One group of *T. bifasciatum* included four juveniles, two large but still yellow phase individuals, and two or three blue-headed males. This group ranged over about 100 square yards throughout the stay. The only cleaning observed was by the juveniles, and then only when they were separate from the rest of the group. This was obviously some soft of social group that remained intact for at least 2 weeks, but its characteristics are not understood.

The total density of cleaner fish was 1–2 orders of magnitude greater than that found in the tropical Pacific.

Ectoparasite Load

Procedure.—Fishes were speared from the reef face at about N 90, E 50 for ectoparasite assay. They were sealed individually in plastic bags within seconds after spearing because the more mobile ectoparasites will drop off a moribund fish. The fish's fins, body, gills, and the residue filtered from the plastic bags were examined with a dissecting microscope.

Results.—The results show a high degree of infection by ectoparasites. It should be noted that the large esopods that are so dramatically noted on the reef fishes account for only a small percentage of this sample. The cleaner fishes predation in estoparasites suggests that the production rate of parasites is 1–2 orders of magnitude greater in the tropical Pacific.

The above data and behavior observation suggest that cleaning symbiosis is a true mutualism in the study areas and that cleaners may well be vital to this ecosystem.

Mission 5

Principal investigator.—J. Miller, NOAA, MUS&T office.

Date.—Apr. 24-May 4, 1973.

Introduction.—Mission 5 encompassed several individual projects ranging from ocean floor biological surveys to nuclear physics experiments. This report describes three studies: (1) Field Validation of Upward Vertical Excursion Diving Tables, (2) Underwater Color Visibility, and (3) Cosmic Ray Physics. Each study, though carried out on site by the team of mission 5 aquanauts, was to a large extent planned by cooperating scientists as part of broader investigations. The principal coinvestigators for the three studies were R. Hamilton, Union Carbide Corporation (Field Evaluation of Upward Vertical Excursion Diving Tables); J. Kinney, Vision Branch, Naval Submarine Medical Center (Underwater Color Visibility); and P. Kotzer, Department of Physics, University of Washington (Cosmic Ray Physics).

FIELD EVALUATION OF VERTICAL EXCURSION DIVING TABLES

Background.—The basic decompression tables developed by the U.S. Navy, other countries, and private organizations are based on computations that assume that the diver is already saturated on air at a pressure of 1 atmosphere. The computations further assume that all vertical excursions will be downward and expose the diver to increasing pressures.

When the diving platform is itself submerged, e.g., an ocean floor laboratory, both ascending and descending excursions are possible. This added degree of freedom complicates an already complex situation with regard to breathing media, excursion times, decompression, and repetitive diving. If, however, maritime scientists of the future are to operate safely and effectively in an underwater environment, we must further our knowledge of diving from submerged platforms.

The Union Carbide Corporation, Tarrytown, N.Y., under contract to NOAA's Manned Undersea Science and Technology Office, has recently developed new vertical excursion diving tables. These tables are designed for use by aquanauts saturated on a normoxic (a mixture having the same oxygen partial pressure as on the surface) mixture of nitrogen-oxygen and making excursions breathing air. Tests were made in Union Carbide's hyperbaric chambers using subjects saturated at depths of 30, 60, 90, and 120 feet. Extensive medical and psychological experiments were carried out in cooperation with the Navy during these chamber studies. As a result, excursion tables (table 12) were made available to the aquanauts of mission 5 for field testing.

Although tables have been developed for both ascending and descending excursions, the bottom topography in the vicinity of the habitat permitted only ascending excursions to be tested. Bottom times of over 6 hours are permissible with no decompression at depths to 180 ft when saturated at a depth of 100 ft, and the maximum depth within a safe swimming distance from the habitat was about 130 ft.

Table 12.—*Maximum permissible time at depth, ascending from habitat saturated at partial pressure oxygen of 0.21 atmospheres, breathing air* [1]

Dive depth[2]	Habitat depth (ft of seawater)— 80	85	90	95	100
Ft of seawater	*Min*	*Min*	*Min*	*Min*	*Min*
65	([3])	([3])	([3])	60	60
60	([3])	([3])	60	55	42
55	([3])	60	55	40	32
50	60	50	40	31	26
45	47	37	31	24	19
40	37	30	24	18	13
35	29	23	18	12	7
30	22	17	12	7	2
25	16	11	7	2	0
20	10	5	2	0	0
15	5	0	0	0	0

[1] Ascend at 30 ft/min, return at 60 ft/min. Excursion times given do not include ascent or descent time. For slower ascents and descents, subtract the extra time used from the excursion time in the table.

[2] Do not ascend sooner than 18 hr following a descending excursion.

[3] No time limit.

Procedure.—Once each day an upward excursion was made by 2 or 3 divers. On each excursion the divers followed the habitat umbilical upward to the prescribed depth and maintained physical contact with the umbilical for the entire excursion. Wrist depth gages were used which were checked daily with the master gage in the habitat. The ascent rate was approximately 30 ft per min. All excursions were made breathing air from either a standard set of double cylinders or a hookah (breathing hose) attached to the habitat.

The excursions were made using the times shown in table 12 based on a saturation depth of 95 ft. The divers constantly checked the time during each excursion and questioned one another for any signs or symptoms of bends. On long excursions the time was passed observing local reef and other inhabitants. Excursions were made on 10 successive days at times selected to be compatible with other planned activities. Visibility and current conditions varied. The maximum current experienced during an excursion was 0.8 knots.

Results.—Twenty-three man-excursions were made during mission 5. Two excursions each were made to depths of 25, 30, 40, 50, and 60 ft. Table 13 gives a brief summary of these excursions and their results. In general no real bends were noticed, although a few niggles were observed by one diver during some excursions. These symptoms are noted in the table.

Table 13.—*Results of vertical test excursions from PRINUL habitat, saturation depth 95 ft*

Dive depth	Duration	Habitat mix, N/O_2	Equipment	No. of divers	Symptoms
Ft	*Min*				
60	55	96/4	Hookah	2	None.
60	55	95/5	do	2	Niggle, right knee.[1]
50	30	90/10	do	2	Niggle, left elbow.
50	31	95/5	Scuba	3	None.
40	18	94/6	do	2	Slight niggle, right knee.
40	18	96/4	do	2	None.
30	7	94/6	do	2	Do.
30	7	95/5	do	3	Niggle, right knee.
25	2	95/5	do	3	Niggle, left elbow.
25	2	93/7	do	2	None.

[1] Same diver each time.

Conclusions.—The absence of significant problems during either the laboratory studies or the field validation reported here suggests that the excursion tables developed are safe for use under the conditions prescribed. As more information on vertical excursion profiles becomes available, it will enable selection of the most effective depths at which to emplace ocean floor laboratories. Also the upward excursion data will add to the margin of diving safety by demonstrating the depth limits from which divers can surface briefly if they become lost, regain their bearings, return to the sea floor, and swim back to the habitat without experiencing the bends.

It should be kept in mind that upward excursions are short decompressions in themselves and should not prejudice subsequent dives, either ascending or descending. Upward excursions, however, should not follow downward excursion by less than about 18 hr.

UNDERWATER COLOR VISIBILITY

Background.—The vision laboratory of the Naval Submarine Medical Center, New London, Conn., has over the past few years been studying underwater visibility. The purpose is to determine what colors are most effective underwater for detection, retrieval, and concealment. Investigations have been carried out in a number of ocean, river, and fresh water locations. Mostly the observations were limited to relatively shallow water because of restricted bottom time and the usual problems of repetitive diving from the surface. Mission 5 afforded an opportunity to make repeated observations under natural illumination, over a 2-week period, at a depth of

about 100 ft. The resulting data were forwarded to New London for detailed analysis and inclusion in the Center's program of underwater visibility.

Procedure.—Four flat targets were set up on the sea floor for viewing from the living compartment port. The flat targets, painted color squares on gray aluminum, were placed on tripod stands at distances of 32, 48, 64, and 80 ft from the habitat so that the target faces were perpendicular to the line of sight from the port. The targets were sized to subtend the same visual angle at all four distances. Eighty feet seemed to be the maximum horizontal visibility on most days. The distances selected thus represented a meaningful sample of color visibility in this location. Six colors were used: black, gray, white, green, fluorescent green and fluorescent yellow-orange.

A second series of targets was a stack of four buoyant, painted spheres tied to a single line anchored to the bottom. This arrangement was placed 40 ft from the port so that the center of the array was at eye level when viewing from the port. Figure 22 shows the arrangement and color configurations of the targets.

The colors were selected on the basis of previous research, predictions to be checked, and questions to be answered under field conditions.

—Black and white were included on each target to determine which was more visible and if this changed with distance. Also they were chosen to insure equal contrast with gray background in air.

—Fluorescent yellow-orange was selected because it should be highly visible at close distances; visibility should be poor at far distances.

—Gray was chosen as an example of a low-visibility color.

—Green was chosen because it is one of the most effective colors for clear water. Fluorescent and regular green were compared.

—A gray background was selected for all colors to permit the specification of contrast no matter what unforseen conditions arose.

The same colors were used for the spherical targets viewed against the water background, a technique used in previous research on underwater visibility. Data were collected three times each day, at approximately 0800, 1200, and 1700 hours, by each aquanaut observing the targets through the port. The task was to note, in rank order on a data sheet, which colors were most visible for both the flat and the spherical targets, including any target not visible at all. There were a few days near the end of the mission during which observations were not possible because high currents kept pushing the flat targets over.

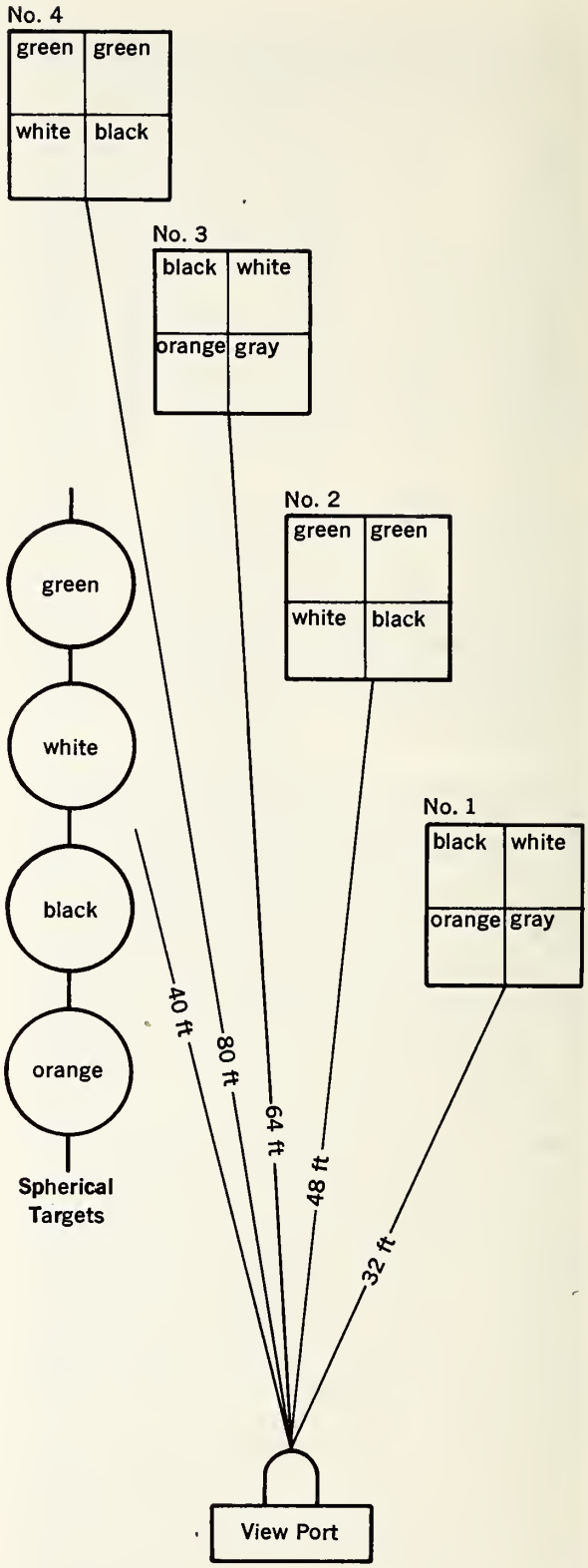


Figure 22.—Arrangement and configuration of underwater color targets.

The targets and the port were wiped off each day to prevent a gradual buildup of algae, etc., which would affect the visibility measurements.

Results.—Eight hundred and eight observations were made on nine days at times ranging from 0800 to 1900. For the spherical targets the overall ranking of color visibility from best to worse was fluorescent green, white, fluorescent orange, and black.

An interesting finding was that the fluorescent green seemed to become more visible and the fluorescent orange less visible later in the day. This could be the result of increased plankton or other particulate matter in the water. Marked changes in current velocity and direction were noted each day which did affect visibility in general and could cause the apparent variation in color transmission.

The results for the flat targets were clear. Black was the most visible color under all conditions except for the closest target. Fluorescent orange was the most visible color in this case. The difference in the color visibility between the spherical and flat targets is probably due to the background against which the targets were viewed. The flat targets were viewed against a light sand background which resulted in maximum contrast with the black square. The spherical targets, on the other hand, were viewed against the water background which made the fluorescent green the most visible.

COSMIC RAY PHYSICS

Introduction.—The detection and analysis of cosmic ray muons and other high-energy particles originating in outer space has been the subject of study by nuclear physicists for many years. A chronic problem, however, is that the signal-to-noise ratio is commonly reduced by the impingement of unwanted particles on the recording surface. Because a water mass between the recording surface (a special photographic emulsion) and the sky acts as a filter, the data are greatly enhanced when the emulsion is prepared and emplaced on the sea floor. For this reason an experiment was designed to prepare and place a specially packaged emulsion on the sea floor for several months to record the rate of impact of certain high-energy cosmic particles. The habitat was chosen because it offered a dry environment for preparing the emulsion with 100 ft of seawater overhead to act as a filter.

Procedure.—A special, unexposed liquid emulsion in a light-proof bottle was placed in the habitat prior to the mission. Practice sessions were carried out on the surface to perfect the technique of setting up and packaging the emulsion.

On the fourth evening of the mission the procedure was carried out in completely darkened living quarters according to the established guidelines using only a special darkroom yellow light. A check of the emulsion the following morning revealed that humidity, temperature, and pressure had prevented it from setting up properly. A second attempt was made several days later, but with similar results.

Conclusion.—Although this experiment failed because of conditions in the habitat, the technique of using undersea platforms for such experiments is valid. Subsequent studies have shown that slight modifications in procedure or in the selection of the emulsion should make a success of such experiments in the future using an ocean floor laboratory.

BRITISH HONDURAS BARRIER REEF INVESTIGATION

This mission was the second of a series conducted near the 200-mile barrier and atoll reef complex off Belize, British Honduras.

Principal investigator.—R. Ginsburg, University of Miami.

Associate investigator.—N. James, University of Miami.

Location.—Glovers Reef, British Honduras, off Belize (fig. 23).

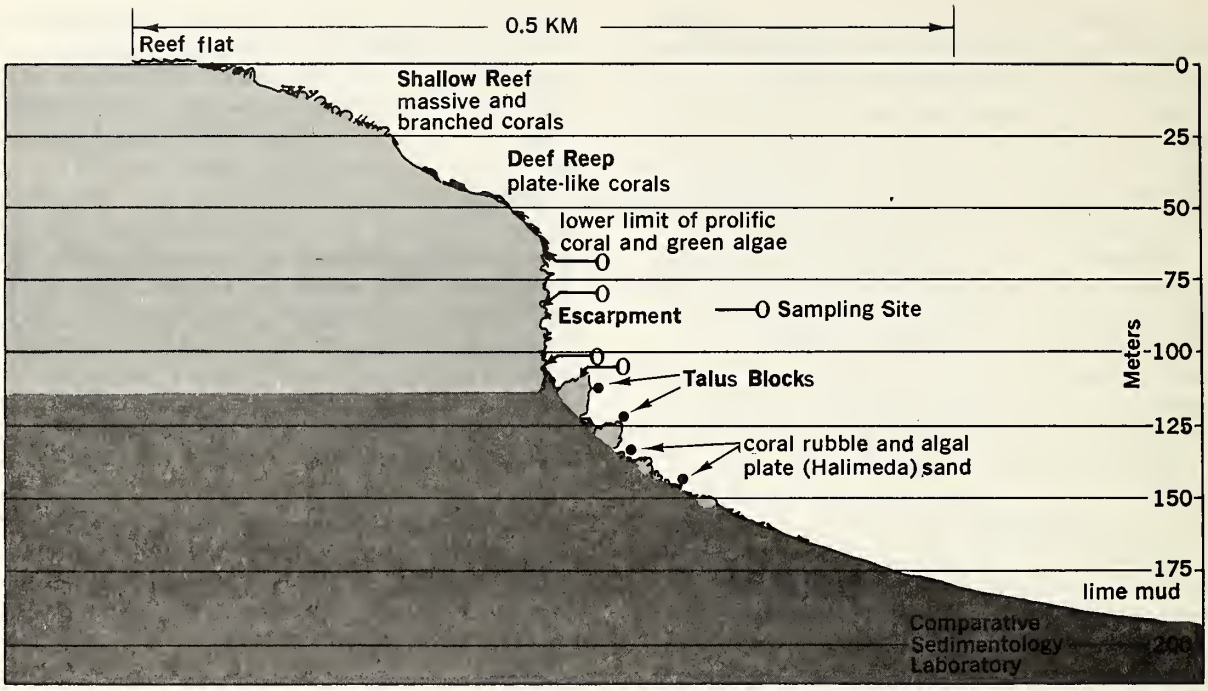
Date.—Oct. 10–30, 1972.

Facilities used.—Research submersible *NEKTON BETA*.

Objective.—A detailed investigation of the dynamic and static processes and general ecology and history of the living reefs.

Procedures and results.—The diving program revealed detailed profiles of the fore-reef, determined the depth of reef-building organisms, and recorded many new features of downslope sediment movement. Using special explosives planted at selected sites with the submersible, over half a ton of rock samples from 11 sites, to depths of 190 m, were obtained.

The complex of barrier and atoll reefs off Belize, British Honduras, is 200 km long, a Caribbean equivalent of the Great Barrier Reef of Australia. Four sites on the barrier reef and three on Glovers Atoll were studied. On the barrier reef, luxuriant growth is concentrated not only in the surf zone but also just above the top of a near-vertical escarpment near 70 m. Growth in the deeper zone is surprisingly luxuriant and covers most of the exposed surface. Lush bushes of the green algae *Halimeda* sp. thrive between large colonies of overlapping thin platey coral as wide as 2 m. The top of the escarpment marks the lower limit of prolific coral and algae growth; below, physical sedimentation and pervasive subsea cementation predominate.



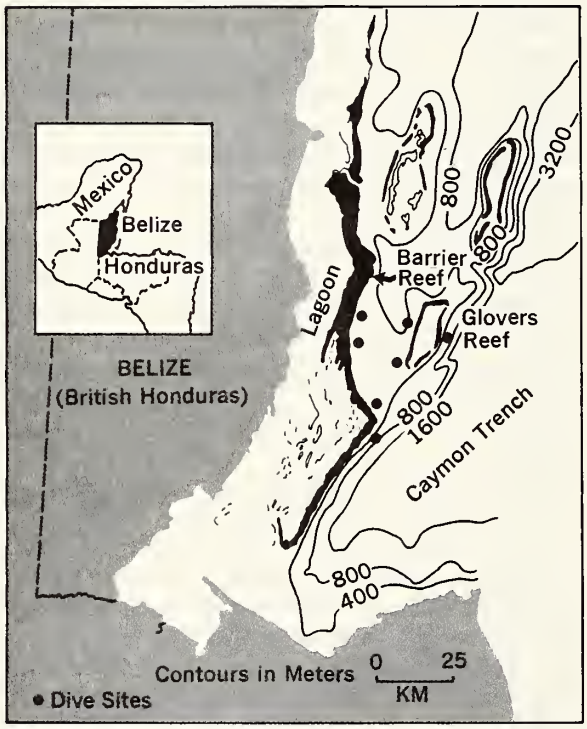


Figure 23.—Dive sites and vicinity of British Honduras barrier reef investigation.

The escarpment has numerous projection ledges, caves up to several meters deep, and joints and open fissures up to 15 m long. This irregular surface is mantled and infilled with sediment from above. Sticks and plates of coral are perched on the ledges; mixed lime mud and lime sand of algal plates cover all near-horizontal surfaces like snow on mountains; lime mud floors the many caves and fills smaller voids. Vertical surfaces of the escarpment are veneered by crustose coralline algae. Living in the shelter of projecting ledges are numerous sponges, occasional stalked crinoids, and red and orange sclerosponges, believed by some to be living counterparts of the extinct stromatoporoids.

Samples from the outer several meters of the escarpment are well-cemented mixtures of coral fragments, phylloid algal (*Halimeda*) plates, and lime mud. Several episodes of sedimentation, cementation, and boring are visible in almost every specimen. These repeated generations of alteration obliterate much of the original depositional fabric. The cement is high-magnesium calcite and aragonite, similar in form and composition to that known from shallow reefs and seamounts.

A sample of unaltered aragonite coral embedded in well-lithified limestone from near the surface of the escarpment has a radiocarbon age of 2,000 years BP.[9] Six samples of similar corals collected from

[9] BP: Before Present, a convention commonly used in radiocarbon dating.

1–3 m within the rock wall between 70 and 110 m have radiocarbon ages between 5,000 and 10,000 years BP. Clearly the outer meters of the escarpment are a Holecane accretion. Most cement is inter- and intraparticle, but so abundant and pervasive that the resulting rock is as hard as any fossil limestone. At several sites the cement occurs in another, entirely unexpected form. Dense, radiating fibrous growth of aragonite of a thickness to 1 cm lines and fills cavities in well-cemented rock. The mammary surfaces and radial structure closely resemble cave deposits, yet the aragonite has oxygen isotope ratios indicative of precipitation in marine waters.

On the barrier reef and the upper fore-reef rise at the base of the escarpment is a talus slope of limestone blocks surrounded by coral plates, *Halimeda* sand, and lime mud. Talus blocks, tens of meters high, are clearly derived from the escarpment; all stages in their formation are visible from jointed rock face through slumped to detached blocks. Within 0.1 km of the base of the escarpment the size and abundance of talus blocks and coral plates decrease abruptly, and algal plate (*Halimeda*) sand is increasingly diluted by pelagic muds.

The vertical escarpment on Glovers Atoll flanking the Cayman Trench has a smooth rock wall to a depth of about 150 m. Below, the slope decreases to about 60° and is mantled by perched talus of coral plates and algal plate (*Halimeda*) sand. The rock beneath this veneer of contemporary talus is well-cemented talus of *Acropora palmata* and other shallow-water corals that have a radiocarbon age of 7,500–8,500 years. Between depths of 180 and 220 m this cemented talus displays ridge and furrow structures oriented downslope like gravel streams on an alluvial fan.

These first results from the deep fore-reef suggest that rapid cementation of lime mud, sand, and gravel may be significant processes in preserving the steep marginal slopes of reefs and carbonate platforms.

International Activities

During FY 1973, extensive discussions began with German Federal Republic (FRG) marine scientists to lay a base for U.S.-FRG cooperative undersea research. The initial and modest objective was U.S. diving participation in the summer of 1973, in the Helgoland cold water underwater laboratory (UWL). Discussions were also held on the feasibility of transporting the UWL to the U.S. northeast coast for joint biological underwater experiments and on the possibilities of diving and habitat technology exchange.

Substantial discussions also began between U.S. and French marine scientists in preparation for a FY 1975 bilateral mid-Atlantic Ridge experiment. This will involve a U.S. submersible, the *ALVIN*, and the French submersible *ARCHIMEDE*. A meeting was held May 7–9, 1973, at Miami, Fla., to discuss cooperative programs in oceanography. These include, besides French-American Mid-Ocean Undersea Study (FAMOUS), such considerations as ocean pollution, instrument standards, data buoys, aquaculture and mariculture, and man-in-the-sea. Various liaison and working groups and key scientist roles for each nation were established, and problem areas defined and clarified.

During late FY 1973 plans and programs were developed for U.S.-Japanese underwater marine research endeavors. An important element in this planning was the exchange of scientists and information in the field of diving technology and physiology. A cooperative diving experiment was planned under the aegis of the Japan Marine Science and Technology Center (JAMSTEC) and the University of Hawaii. The experiment was planned for July 1973 and will be described in the FY 1974 report.

Participants in Scientific Programs

UNITED STATES NORTHEAST COAST FISHERIES SURVEYS

Ecology of deep water lobsters.—R. Cooper, J. Uzmann, K. Pecci, W. Whipple.
Spawning and early life history of herring.—R. Cooper, H. Boyar, J. Uzmann.

HUDSON CANYON INVESTIGATIONS

G. Keller (and eight other participants).

BAHAMA BANKS RESEARCH INVESTIGATIONS

Mission 1.—J. Bunt, A. Cobet.
Missions 2, 5, 9, 12, 16, 22, 27.—J. Bunt, M. Wells, A. Ikehara, I. Strickland, B. Soester, R. Trumbull, C. Lee, D. Wilson, S. Pepper, Z. Mount, T. Mount, Z. Sendry, S. Earle, J. Vaught, L. Vaught, J. Banbury, M. Bonsignore, R. Smith, S. Cawthon, J. Wright, D. Malloy, S. Exley, R. Frehsee, P. Reinholm.
Missions 3, 7, 10, 18, 24.—E. Corcoran, R. Curry.
Missions 4, 8, 26.—W. Schroeder.
Mission 6.—M. Heeb.
Mission 11.—P. Cratin.
Mission 13.—S. Earle.
Mission 14.—A. Allen.
Mission 15.—W. Muellenhoff.
Missions 17, 20.—J. Lord, P. Kotzer, K. Stehling.
Mission 19.—C. Smith.
Mission 21.—K. Ackles (and others).
Mission 23.—A. Roth.
Mission 25.—T. Bright, T. Burke, C. Tresslar.

PUERTO RICO INTERNATIONAL UNDERSEA LABORATORY (PRINUL) RESEARCH PROJECTS

Mission 1.—J. Wells, D. Olsen, M. Sheen, J. Larson.
Mission 2.—A. Dahl.
Mission 3.—B. Harger.
Mission 4a.—G. Barlow.
Mission 4b.—G. Losey.
Mission 5.—J. Miller.

BRITISH HONDURAS BARRIER REEF INVESTIGATION

R. Ginsburg, N. James.

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